



Science and the Planet Earth I





The Open University
Science: A Foundation Course

Unit 1

Science and the planet Earth I

Prepared by the Science Foundation Course Team

The Open University Press

S101 Course Team List

A note about the authorship of this text

This text is one of a series that constitutes a component part of the Science Foundation Course. The other components are a series of television and radio programmes, audio-vision materials, home experiments, assignments and a summer school.

The Course has been produced by a team, which accepts responsibility for the Course as a whole and for each of its components.

The Science Foundation Course Team

Mike Pentz (*Chairman and General Editor*)

Francis Aprahamian (*Course Editor*)
David Broadhurst (*Physics*)
Geoff Brown (*Earth Sciences*)
Neil Chalmers (*Biology*)
Glen Davey (*Course Coordinator*)
Graham Farmelo (*Physics*)
Peter Francis (*Earth Sciences*)
Stuart Freake (*Physics*)
Anna Furth (*Biology*)
Denis Gartside (*BBC*)
Charles Harding (*Chemistry*)
Keith Hodgkinson (*Physics*)

Stephen Hurry (*Biology*)
David Jackson (*BBC*)
David Johnson (*Chemistry*)
Tony Jolly (*BBC*)
Roger Jones (*BBC*)
Patricia McCurry (*BBC*)
Perry Morley (*Editor*)
Jane Nelson (*Chemistry*)
Ian Nuttall (*Editor*)
Irene Ridge (*Biology*)
David Roberts (*Chemistry*)
Shelagh Ross (*Course Coordinator*)

Eileen Scanlon (*Research Fellow, Evaluation*)
Milo Shott (*Physics*)
Jacqueline Stewart (*Editor*)
John Stratford (*BBC*)
Steve Swithenby (*Physics*)
Peggy Varley (*Biology*)
Kiki Warr (*Chemistry*)
Barrie Whatley (*BBC*)
Dave Williams (*Earth Sciences*)
Chris Wilson (*Earth Sciences*)

The following people assisted with particular parts or aspects of the Course:

Tel Bailey (*Tutor*)
Mary Bell (*Biology*)
Frances Berrigan (*IET*)
James Brennan (*Biology, Bridgewater State College, USA*)
Joan Brown (*Earth Sciences*)
Bob Cordell (*Biology*)
Beryl Crooks (*IET*)
Linda Fawke (*Tutor*)
Michael Gagan (*Chemistry*)
Ian Gass (*Earth Sciences*)
Ros Hamilton (*Tutor*)
Robin Harding (*Biology*)
Barbara Hodgson (*IET*)

Jen Horgan (*Tutor*)
Graham Jenkins (*Earth Sciences*)
Barrie Jones (*Physics*)
Paul Lyle (*Tutor*)
John Marshall (*Senior Counsellor*)
Bob Maybury (*Chemistry, UNESCO*)
Bob McConnell (*Earth Sciences, Virginia Polytechnic and the State University, USA*)
Laurie Melton (*Librarian*)
Reg Melton (*IET*)
Yow Lam Oh (*Home Experiments, Caulfield Institute of Technology, Australia*)

Robin Russell (*Chemistry*)
Meg Sheffield (*BBC*)
Jane Sheppard (*Designer*)
Jennie Simmons (*Home Experiment Kit Coordinator*)
Peter Smith (*Earth Sciences*)
Russell Stannard (*Physics*)
Charles Turner (*Earth Sciences*)
Arthur Vials (*BBC*)
John Walters (*Physics*)
Pete Wood (*Home Experiment Kit Coordinator*)
John Wright (*Earth Sciences*)
Martin Wright (*BBC*)

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Contents

Study guide

Study guide	2
Table A List of terms and concepts used in Unit 1	4
Introduction	5
1 What is science?	6
1.1 Science as a social activity	6
1.2 The scientific method	8
1.3 Aspects of scientific reasoning: a vocabulary of terms	9
1.4 Summary of the Introduction and Section 1	13
2 What shape is the Earth?	13
2.1 The pancake model	13
2.2 The spherical model	14
3 The Earth and the Universe—everyday experience and observations	18
3.1 Days and nights	18
3.2 The four seasons	18
3.3 The Sun and the Moon	19
3.4 The stars and the planets	20
3.5 The periodicity of events	21
3.6 Summary of Section 3	23
4 The Earth and the Universe—building a model	23
4.1 The Earth and the Sun	24
4.1.1 Two kinds of circular motion	25
4.1.2 What causes the day–night cycle?	26
4.1.3 What could explain the seasonal cycle and its local variations?	28
4.1.4 Which of the two bodies is orbiting—the Sun or the Earth?	31
4.2 The Moon and its relationship to the Earth and the Sun	33
4.3 The Earth and the stars	39
4.4 A summary of the model	40
5 A short concluding discussion	41
5.1 Assumptions of the model	41
5.2 What makes a good model?	42
5.3 What next?	42
Aims and Objectives	44
ITQ answers and comments	45
SAQ answers and comments	46

Study guide

This first Unit of the Science Foundation Course consists of three main components:

the core text of the Unit, referred to as the Main Text;

the TV programme (TV 01);

the audio-visual sequence (AV 01).

Related to these main components are three additional items:

the first Tutor-Marked Assignment (TMA 01);

the first Computer-Marked Assignment (CMA 41);

a radio programme (Radio 01).

Two of these (TMA 01 and Radio 01) will partly overlap with the second Unit of the Course; CMA 41 covers Units 1 to 3.

Those of you who have not been studying regularly for some time may feel somewhat overwhelmed by this seemingly complex array of material. You will find out gradually that there are very good educational reasons for it. And you will develop your own ways, best suited to your own conditions and temperament, of making the most of the material with the least effort and the minimum waste of time. In the meantime, however, here is what the Course Team would recommend as good strategy for tackling Unit 1, and a guide to its various components.

(a) *The audio-visual sequence (AV 01)*

Have a quick run through AV 01. Do not be put off by the fact that some words may not mean much to you, or that you do not understand either the pictures or the accompanying commentary. All you should achieve in this first step is to learn how to use the filmstrips and the tape, and to have a *preview* of the material that you will find in the Main Text.

(b) *The Main Text*

Study the Main Text thoroughly. Do not skip the little experiments, no matter how simple and even childish they may seem. Attempt all questions in the text before you read on.

These questions are designed to involve you *actively* in the development of the argument of the text. This is preferable to straight, passive reading. You will find that, in attempting to answer them, you will have to rely on, or refer to, some material already discussed; but often you will also be asked to make a step forward, even if only in the form of a guess.

Answers to unnumbered questions in the text are normally provided within the text, usually immediately after the question. This is to enable you to check quickly whether you got your own answers right and to correct any mistakes or omissions that you may have made and that might hinder your understanding of the subsequent text. Answers to numbered in-text questions (ITQs) can be found at the back of the Main Text.

Self-assessment questions (SAQs) are designed, as the name suggests, to enable you to assess for yourself whether you understand the main terms and concepts introduced in the Unit or whether you have developed the particular skills or techniques listed in the Objectives of the Unit. Answers and comments for all SAQs are provided at the back of the text.

(c) *Main Text, Section 1.3*

This Section has a special place in the Unit. It is impossible to give absolutely perfect definitions of the terms listed. Moreover, the understanding of these terms cannot be gained by reading and memorizing such definitions, even if it were possible.

At the same time, it is necessary for you to start to cultivate your awareness of these different aspects and techniques of scientific thinking right from the beginning. Thus, in some way, you are facing a chicken-and-egg situation. In order to develop and improve scientific reasoning, you should be able to distinguish between assumptions and observations, inductive and deductive statements, aspects of a scientific model and hypotheses (predictions). But you cannot really appreciate what these things mean without referring to practical

examples taken from actual scientific problems that you have not as yet studied.

Obviously, there has to be a compromise. The vocabulary of terms in Section 1.3 is formulated mostly in terms of everyday language and does not pretend to be complete and perfect. Even so, in some cases it is quite unavoidable to list examples from different fields of science and to use some technical terms (such as atoms, cells, species, energy, gravitation, electromagnetic waves, inheritance, natural selection, electrons, plate tectonics, etc.) which cannot have a clear, well-defined meaning at this stage.

Please take our advice and, at this stage, *read through Section 1.3* just once, without attempting to clarify each and every word or sentence that you may find difficult, puzzling or downright incomprehensible. This Section is meant to be used for later reference and, in particular, for your final revision after you have been through the whole Course.

(d) *Main Text, Sections 2, 3 and 4*

These Sections contain the main message of the Unit. You will not find any Earth-shattering discoveries, but please bear in mind that the emphasis is not on the *facts* but on the *ways of thinking* about them. You may find that it is quite difficult to visualize in three dimensions the mutual positions and motions of two or three spherical bodies, representing the Sun, the Earth and the Moon. The illustrations in the text can go some way in helping you but, if you are having difficulties, please refer to the filmstrip in AV01. The use of colour and some slight differences in the method of illustration may help you on. And the TV programme will provide additional reinforcement of your understanding of Foucault's pendulum (spin of the Earth), phases of the Moon (relative motions of the Moon around the Earth) and of the apparent reversals in the progression of planets.

(e) *The TV programme (TV01)*

This programme can only be useful to you *after* you have studied the Main Text of the Unit. So, please make sure that you get your timing right, check the transmission dates now, and allow at least 5–6 hours for the first reading of the Main Text during the week before the first transmission of TV01.

(f) *How to tackle the assignments*

After you have watched TV01 and worked through the Main Text, including its experiments and questions, you should be in a position to consolidate what you have learned, by running through the audio-visual sequence once again. This time you should be able to follow and to understand the whole story. If not, glance again at the corresponding parts of the Main Text.

Finally start working on TMA01 and CMA41. Remember that all TMAs and CMAs are *open-book* exercises. You are not only allowed, but positively encouraged, to refer to any part of the Course Unit (Main Text, TV, radio, AV sequence) in answering the questions. You are also encouraged to discuss the questions with your fellow students and/or with your Study Centre Tutor-Counsellor. These discussions can help you to clarify the problems and guide you in seeking for the correct approach. But we expect that the final step, the actual formulation of answers, will be *your own effort*. The real value of TMAs and CMAs is not so much in the grades you get for them; after all, each of them represents only a very small part of the overall assessment. Their value lies in their effect on your study techniques. Continuous assessment is the best way to maintain your level of study and to prepare for the final Course examination.

In the whole sequence of continuous assessment, *TMA01* has a special place. It is designed to *introduce* you to the way of writing and submitting the TMAs, without your paying any penalty for your lack of previous experience. Your Tutor-Counsellor will grade the assignment and comment on it as if it were the same as any subsequent TMA. But this time it will not matter if your grade is low; it will not count against your overall continuous assessment grade. We hope that this will eliminate any initial anxiety that you might feel. At the same time, it will give your Tutor-Counsellor a chance to offer you help and advice on how to write future assignments.

Well, this has been quite a long study guide; you won't find one as long as this in later Units. It repeats some of the points made in the *S101 Introduction and Guide*, which you can refer to, if necessary, when you study those Units.

TABLE A List of terms and concepts used in Unit 1

Assumed from general knowledge	Introduced in the Unit	Page No.
altitude	assumption	9
astronomy	axis of spin	25
celestial	culmination	18
circle	deduction	11
cone	geocentric	17
constellation	heliocentric	31
cylinder	hypothesis	10
environment	induction	10
energy	law	11
experience	lunar phases	20
horizon	model	12
identical	orbital motion	25
inclined	period	21
instrument	periodic (motion, process)	21
latitude	planet	21
line (straight line)	Pole Star (Polaris, Northern Star)	20
longitude	retrograde (motion, loops)	21
observation	scientific method	8
pancake	sidereal day	34
pattern	solar day	18
parallel	spin	25
pendulum	theory	12
perpendicular		
plane		
qualitative		
quantitative		
season		
senses		
separation (of two bodies)		
sphere, hemisphere		
star		
synchronized		
technology		

Comment

In this Table, the terms listed in the first column (Assumed from general knowledge) are used in the text without being explained or defined. Some of them have a sufficiently clear meaning in everyday language; in other cases, their exact meaning is not critical to the understanding of the context in which they are used. If some of them are new to you, please refer to any dictionary or encyclopedia, and the simple explanations you will find there will be quite sufficient.

The terms listed in the second column (Introduced in the Unit) are either defined in the text or explained by examples. Understanding of their meaning will be assumed in the future Units of the Course.

'The whole of science is nothing more than a refinement of everyday thinking.'
(Einstein, *Physics and Reality*, 1936)



The planet Earth (a black-and-white copy of a NASA photograph, taken 21.1.1968 from ATS 3 satellite).

Introduction

The photograph of the planet Earth reproduced here was taken in 1968 from a spacecraft at a distance of some 38 000 km (24 000 miles) from the Earth. It is a testimony to one of the great achievements of science and technology in the twentieth century and for this reason alone it deserves a place in an Introduction to a Foundation Course in Science.

The photograph represents a crowning-point in man's direct exploration of his environment. There is no doubt that man's curiosity is the most elemental, the most basic, driving force behind science. *The quest for knowledge* is an integral part of human nature. It may have different forms, different degrees of intensity and different manifestations in different people and at different stages of individual or social development, but it is always there, and very often the sheer pleasure and satisfaction derived from the acquisition of new knowledge provide sufficient motivation and justification for the efforts needed and hardships suffered in obtaining it.

However, there is more to it than this. Whereas most people would probably appreciate the achievement of space exploration and share in the thrill of looking at the likeness of Mother Earth, many would also ask: 'But is it worth all the money and effort?'

A query such as this brings to the fore the *social context* of science. Although the desire to know, to understand, is a feature of individual human character, the actual process of acquiring knowledge is not an isolated, individual activity. It is based on man's interaction with his environment, on his doing things in response both to the needs imposed by material living conditions and to the pressures created by social relations and structures. Conversely, when new knowledge is acquired and applied, it could lead to important consequences for the man's natural environment and for the way of life of human societies. Thus, to query the value and the cost of any particular scientific achievement is not only a legitimate attitude but a very desirable one.

Returning to the photograph of the Earth once more, for many people it probably represents a real proof that the Earth is round. This relates closely to the question of *scientific method*. Why does the old saying 'seeing is believing' carry so much weight? It has been known for centuries that the Earth must be round, although nobody could actually see this until space-travel became possible. And yet the

evidence of direct observation obviously has a more powerful impact than conclusions reached by reasoning. So, is it always necessary to have such direct evidence, based on the human senses, in order to understand things? Moreover, is this evidence always completely reliable? What are the relationships between simple observations, scientific experiments and scientific reasoning?

The photograph of the Earth thus provides a natural introduction to the three aspects of science that will be discussed in different contexts throughout this Course: the quest for knowledge; the social context in which science is practised; and the techniques and methods of scientific enquiry. In the first Section of this Unit you will find a brief outline of some aspects of the social role of science and a description of some terms relating to the scientific method. Please *do not* treat this Section as a collection of truths that you have to memorize. Science cannot be understood or even appreciated by remembering a few statements or definitions. Understanding comes only from doing things and solving problems. As you start working your way through this Course, you will develop, often without realizing it, new attitudes to problems and a new insight that cannot be acquired simply by reading words. Thus the next Section is no more than scene setting. It also contains a vocabulary of terms whose context and meaning will become clearer to you later. At this first reading, it will be quite sufficient if you notice the more specific scientific meaning of some words that you know from everyday language. Thus, for example, induction and deduction are two words which are frequently interchanged in ordinary written or spoken English as if they meant the same thing. This will not do in science. Individual words have a clear, more narrowly defined meaning, and it is essential to stick to it in order to avoid confusion.

1 What is science?

In everyday use, the words 'science' and 'scientific' mean different things to different people. They can be used to describe the *activity* of individuals or teams leading to the discovery of new knowledge. They can also mean the sum of this knowledge, the *content* of scientific books and journals in which acquired knowledge is recorded for posterity. Some people would use the same terms in an *institutional* sense, emphasizing the existence and the activities of research institutions, cooperation between specialized teams of researchers, and the planning and funding of their activities.

In spite of all these nuances of terminology, it is possible to identify at least two common aspects in any human endeavour that can legitimately claim to be of a scientific nature:

- 1 The aim of science is the discovery, description and understanding of new facts about nature (whether on a large scale or a small one, about things living or lifeless).
- 2 The methods of scientific enquiry are based on a combination of observation, experiment and reasoning.

1.1 Science as a social activity

Science plays an extremely important role in the life of industrialized societies. Food and clothing, health and leisure, means of transport and long-distance communications are all strongly influenced by the results of scientific research and by its applications. At the same time, the progress of science can also be linked with the production of more destructive weapons, with increased pollution of air, rivers and oceans, and with the squandering of some rare resources.

Should scientists alone be praised for all things good and pleasant that science brings to our lives, and blamed for all that is bad, destructive and terrifying? Would it be possible to devise some mechanism by which the only scientific research allowed to flourish would be that leading to obvious benefits to mankind? Perhaps scientists themselves should take the responsibility for stopping any research that might lead to the production of weapons or to the destruction of the natural environment?

There are no simple answers to these questions because they necessarily involve moral and ethical judgements. There are, however, some important objective aspects that anyone who considers these problems must keep in mind.

First of all, it is only within the last century that science has become recognized as an organized form of human activity. Before that it was regarded only as a hobby, a pastime for a few privileged enthusiasts. But people were perfectly capable of producing tools and goods and improving their quality without having any scientific background. Glass and metals were produced by our distant ancestors, and receptacles, tools and weapons made from them, without any knowledge of the physics and chemistry involved. The desire to improve one's life, and an ability to do so, existed before science. So did the evil streak in human nature that led to the destruction of life. Science did not create social problems, it merely made them more acute. Even if it were possible to stop and abolish science, they would not go away.

The next thing to consider is that it is no more possible to stop the development of science than it is to stop the development of man. The quest for knowledge is so much a part of human nature that it cannot be curbed without changing or destroying human nature itself. The fact that individual curiosity has become interlinked with social organization makes the position of an individual scientist more difficult, more dependent on the society as a whole. But there is no way of stopping a man from being curious and wanting to know.

Last but not least, it must be realized that most scientific discoveries can be applied *either* for the benefit *or* to the detriment of humanity. For instance, recent research in genetics* could have enormous utility in medicine, but it could also provide the basis for very dangerous biological warfare agents. Indeed, many biochemists feel greatly relieved that significant progress in genetic engineering has been made only since the adoption in 1972 of an international convention prohibiting biological warfare. The question of whether the results of scientific research will be used for good or for evil is not internal to science and cannot be solved by scientists. The answers to it must be sought in the social and political context in which science is practised.

All this does not mean, however, that a scientist can be indifferent to the use or misuse of his work. As the consequences of possible misuses of science are becoming more and more alarming with almost every new major discovery, the feeling of social responsibility weighs more and more heavily on the scientific community. Its concern about nuclear weapons and nuclear energy programmes is just one example. Another example is the active role scientists have played in influencing both public opinion and legislators in favour of the adoption of the convention against biological warfare already mentioned.

There are, however, many other problems, less eye-catching but not less important, where scientific solutions are being sought in the context of complex social and political considerations. These include, for example, the optimum rates of fishing and indeed the optimum rates of exploitation of any other resources, the advantages and disadvantages of different forms of pest control, the choice of different types of nuclear reactors for power stations, the control of pollution, the conservation and optimum use of available fuels and so on. In all these problems, scientists have a moral obligation not only to consider the best solutions and their possible consequences, but also to communicate with their fellow citizens to enable them to exercise their influence on decisions that are eventually taken outside science.

It will be one of the aims of this Course to help you find your own bearings on some of the important issues of today. It will give you a foundation of scientific knowledge that will enable you to appreciate the scientific and technical aspects of such issues. In real life, however, most problems have so many ramifications that the scientifically best solution to one problem may not always be possible, because it would cause intolerable hardship to some section of the public or because it would prejudice the best solution of some other related problem. This complexity makes it even more important to have some insight into the different scientific aspects of any such problem. Although this Course cannot give you ready-made answers, it can help you to find them, or at least to appreciate their merits if proposed by somebody else.

* Genetics is the study of mechanisms by which cells and organisms reproduce themselves. Genetic engineering leads to the development of highly modified or new organisms by influencing individual hereditary variations.

1.2 The scientific method

How is the scientific knowledge obtained? Is the scientific method any different from the way in which ordinary people perceive and discover the world around them?

Every human being, endowed with normal senses of sight, hearing, touch, smell and taste, learns a lot about the world, without ever getting involved in 'doing science.' Most of this commonsense knowledge comes from everyday *experience*: the things we observe and the things we do.

You do not have to be a scientist to know that it is not advisable to touch an object that glows red. You have acquired this knowledge either from repeated unpleasant experience, or—less painfully—with the help of communication from your parents or other experienced people looking after you. To have such knowledge is undoubtedly very useful, if only because it enables you to keep out of harm's way. But it is not the same as understanding *why* a glowing object is hot and how the colour of the glow and the temperature of the object are related. In a similar way, your everyday experience tells you that the Sun never rises at the same place where it set the day before, but somewhere on the opposite side of the horizon. But this observation gives you no clues as to how the Sun got over there and what happened to it between sunset and sunrise.

One could say, somewhat crudely perhaps, that science begins when man tries to reach *beyond* his common observation and experience. The details of how this reaching beyond everyday experience is achieved may be different in different cases, but essentially there are two ways of going about it. One way is to organize new observations and experiences that are not readily available in everyday life. This activity can be broadly called *experimentation*. It usually involves some degree of control over the conditions in which observations are made, so that important relations between objects and their properties are not obscured by accidental, unimportant, interfering circumstances. The second way of reaching beyond everyday experience is by *reasoning*. This involves making a step from the analysis and evaluation of direct evidence, provided by observation and experiment, to a conclusion or statement that is not immediately obvious or observable.

In the development of science as a whole, observations, experiments and reasoning are inextricably intertwined. The results of observations and experiments provide a starting point for the formulation of hypotheses, models and theories (see Section 1.3) by reasoning. But the outcome of such thought processes is again tested by new observations and experiments. So, a highly idealized scheme of a scientific method could be described by the following three steps:

- 1 Everyday experience is supplemented by *systematic observations* and *quantitative measurements*. Such observations and measurements involve the use of agreed *units* for comparing such things as the time intervals required to complete different events or processes, distances between different places, volumes and weights of different objects, etc. In most cases there is a need for the use of *instruments*, to detect signals that human senses cannot detect at all or cannot properly analyse.
- 2 All evidence obtained in this way is carefully recorded (tables of data, graphs) and analysed. The aim is to discover regularities and patterns in the multiplicity of individual data, and, if possible, to suggest a *theoretical model* (see Section 1.3) that would explain all the observations. Moreover, such a model usually leads to *predictions* of new, as yet unobserved, effects or phenomena.
- 3 Predictions based on theoretical models are tested by *experiments*, that is by systematic observations and measurements designed specifically to check whether a predicted effect exists or not. The results of such test experiments sometimes necessitate the rejection of the theoretical model outright, but more often provide additional data for its further refinement or modification.

It would be naïve to think that each and every scientist has these three steps written down or programmed in his mind, and that unless all three steps can be clearly identified in his work he is not doing his science properly. In practice, there are scientists who excel in the collection of data and in the design and realization of experiments, but are not so good at proposing theoretical explanations. At the other end of the spectrum, there are fine theorists who, if put inside a laboratory, cannot tell a mouse from a rabbit or a voltmeter from an oscilloscope (to stretch the point just a bit). Similarly, there are whole branches of science where one or

the other activity predominates. Thus biology and biochemistry produce a glut of detailed experimental results and rather few general theories, whereas in astronomy and cosmology experimental data are scarce compared with the level of theoretical activity. Hence the aspects or steps of the scientific method as listed above are an abstraction from science as a whole and not an actual recipe for becoming a scientist.

In the process of practising science, there are techniques to be learned. Each experimental activity involves some very specific techniques that are advantageous or indeed absolutely necessary if a useful result is to be obtained. Thus there are techniques for isolating chemical substances from solutions, ways of collecting and breeding fruitflies, methods of measuring very short time intervals and procedures for studying earthquakes. These experimental techniques are an absolutely essential part of science, and at different parts of this Course you will be asked to learn some of them. So do not skip your Home Experiments!

Then again, there are also techniques and skills necessary for the analysis of collected experimental data, such as tabulating results in numerical form, plotting them on graphs or expressing them in equations. In the later Course Units, you will see how such techniques help your understanding of what is going on. Formulae, graphs and equations may look foreign and frightening at first, but once you get involved in analysing a particular problem, you will soon discover that they are only a very convenient and helpful language in which to record your results.

Finally, there are certain well-established techniques of reasoning and logical thinking. The next Section presents a short and simple vocabulary of terms that are related to the process of scientific reasoning.

Please do not attempt to memorize any of these descriptions or definitions; but think about them, read the examples (and comments) and try to make up your own. You will be able to check your increasing understanding of these terms if you refer back to this vocabulary as you work through the rest of this Unit, and during your study of the whole Course.

1.3 Aspects of scientific reasoning: a vocabulary of terms

ASSUMPTION A statement about some important factor in an experimental situation or in a theoretical model that cannot be easily proven beyond doubt but can be reasonably expected to be true, or at least approximately true, in the given circumstances of the experiment or model.

assumption

Examples It is sometimes assumed that light travels infinitely fast. This assumption is reasonable where small distances are involved, so that the time interval from the emission of light to its detection is extremely short (e.g. when getting one's bearings from a lighthouse). But it would be a wrong assumption when thinking about stars and planets. It can take millions of years for light to travel from one star to another.

Similarly, in most experiments within an Earthbound laboratory, it is perfectly reasonable to assume that light travels in a straight line. Indeed, our nearest real thing to an ideal straight line is a beam of light. But the same assumption would be wrong where light travels through different media (e.g. air of different densities in the atmosphere) or in close vicinity to very massive objects (e.g. stars).

These examples show how important it is to list any assumptions made in the process of analysing data and deriving conclusions from them. An assumption that seems reasonable at one time may well be shown to be unreasonable later, in new circumstances or with higher demands for accuracy. It is quite easy to decide when the two assumptions about light are reasonable and when they are not, because the velocity of light and its behaviour during propagation are well known. But more often than not, assumptions have to be made when there is no way of being absolutely certain of their validity. You will come across such assumptions many times later.

Practical examples of assumptions made in your everyday life can be found in planning long-distance journeys, registering for your future Open University Courses, and making arrangements for your retirement. In the first case, you assume that your train to London will be on time to catch your connection to Paris; in the second, you register for your future courses on the assumption that you will succeed in the present one; and in the third case you assume that you will

live to enjoy your pension. All these are perfectly reasonable assumptions. May they all prove to be true!

HYPOTHESIS A statement of expectation about the things being studied, which is put forward tentatively, usually on the basis of incomplete evidence, as a reasoned guess.

hypothesis

The formulation of a hypothesis takes into account all that is already known about the object or situation under investigation and tries to identify or predict as yet unknown but possible features and/or correlations between different parts or aspects of the object or situation.

Examples 1 The new Science Foundation Course S101 will be better than its predecessor, S100.

2 Most people would stop smoking if the price of one cigarette were to be fixed at £1.00.

3 Changes of atmospheric pressure cause headaches.

Comments 1 This is a hypothesis at the time of writing this Unit. The Course Team hopes that it will be an established fact by the time you read it. But there is also a possibility that future events may prove the hypothesis to be wrong!

2 There is evidence that increased cost discourages consumption of almost anything. Some people certainly would stop smoking, but how many is anybody's guess: very few—half—most—nearly all? Only an experiment could tell.

3 There is evidence of the simultaneous occurrence of headaches and pressure changes. But simultaneous (or consecutive) occurrence of two effects is not in itself a proof that one causes the other. There may be other factors involved in this coincidence that are less obvious but more important.

As can be judged from the description of hypotheses and from the examples, their main value is that they encourage, invite, initiate experimental activity for their rejection or justification.

INDUCTION (inductive statement, inductive inference) A statement about the properties, aspects or behaviour of a *whole group* (class) of objects or situations, formulated on the basis of direct evidence covering only a *part* of the group (a limited sample of the objects or situations).

induction

Examples 1 *Observation:* The roses in my garden are red. *Induction:* All roses are red.

2 I am not going to like this piece of music by Schoenberg since I have never enjoyed any of his compositions before.

3 The consumption of electric power per household will double within the next ten years.

Comments You will notice from these examples that inductive statements can have very different degrees of credibility and reliability.

1 This is a typical example of what is known in common parlance as jumping to conclusions on insufficient evidence.

2 This is a more subtle example of reasoning by induction. Because I have never enjoyed any composition by Schoenberg, I expect that I shall not like the next one I hear. Often, a similar induction is based on even less reliable foundations, such as information of other people. Most prejudices are examples of (unjustified) inductive thinking.

3 This induction is based on the fact that the consumption per household has doubled over the past ten years. An induction of this kind, where an *observed trend*, or rate of change of some quantity is *projected* into the future (or extended in any other way outside the scope of observation) is known as *extrapolation*.

It is important to note that an extrapolation always conceals a hidden *assumption*, namely that all factors that determined the observed trend will work in the same way in the future or in a different place. In this particular example, the hidden assumption is that the rate of acquisition of new consumer appliances will remain the same as it was over the past ten years. It is an unreasonable assumption, because most households are perfectly happy with one television set, one refrigerator and one washing machine.

Similar examples of unreliable extrapolations include estimates of population based on assumptions about birthrates.

DEDUCTION (deductive conclusion, deductive inference) A statement about the properties or behaviour of *one particular* object or situation (or a limited sample of objects or situations) that follows by simple rules of logical thinking from a statement covering the whole class of objects or situations to which the one under consideration belongs.

deduction

Examples 1 Roses can have any possible colour. Hence some of the roses in my garden can be red.

2 Each sale item in this basket costs £5. Hence the green pullover I like (and which is in the basket) will cost me £5.

3 It is impossible to construct a triangle from three sticks of lengths 1 cm, 2 cm, and 4 cm.

Comments First of all, notice that, in some ways, deduction is the opposite of induction (compare the first examples under both headings). However, there are important differences. Induction extends the applicability of a statement to *new* objects or situations. Deduction, on the other hand, only *specifies* or applies the consequences of a general statement to *one particular* object included in the whole class to which the general statement refers.

An inductive statement always involves an element of risk or doubt. It is possible to make a wrong induction from a true statement (for example by overlooking an assumption whose applicability is limited). On the other hand, only inductive reasoning opens new horizons and sets new problems.

Deductive reasoning is safer. Provided the initial general statement is true, the deduction from it is also true. But it does not offer anything new, it only elucidates the consequences of the initial general statement as they apply to one individual case (Examples 2 and 3).

By the way, it is not a coincidence that Example 3 has a mathematical flavour. Deduction is a standard technique in mathematics by which theorems, statements and numerical results are proven, derived or applied. This particular example, which you are invited to check by playing with matchsticks, or something similar, follows from a general statement that in any triangle the sum of *any* of its two sides is always greater than the third one. The lengths given in Example 3 do not satisfy this condition ($1 + 2$ is *less* than 4) and therefore a triangle with such sides cannot exist.

LAW A statement of relationship between things, covering results of observations and experiments over a wide range of individual cases, to which there are no known exceptions.

law

Examples 1 The law of reflection says that when a beam of light hits a mirror the angle at which the light is reflected is the same as the angle at which it first arrived (for any angle and any mirror).

2 Heat does not flow spontaneously from a colder body to a warmer one.

3 If the temperature of a gas enclosed in a vessel of constant volume is increased, then its pressure against the walls of the container increases in the same proportion.

Comments 1 No doubt you take into account the practical applications of this law when you cast the reflection of the Sun onto a wall or ceiling or onto the face of somebody whose attention you want to catch.

2 You may say, quite rightly, that this statement is no more than just plain commonsense truth. And yet, it is a manifestation of one of the most general and most important laws of nature, which restricts the convertibility of heat into other more useful forms of energy. (In the scientific jargon this law is known as the second law of thermodynamics.)

3 All gases obey this law within a wide range of temperatures and pressures. It is because of this law that you should not throw aerosol containers (such as from hairsprays, car paints and flykillers) into the fire: they still contain gas and its increased pressure may lead to the explosion of the container.

The important point is that laws are not based on assumptions or on hypotheses. They represent condensed formulations of what is actually observed. They are accepted as laws because they are supported by a great deal of experimental evidence and there are no known exceptions to them. Their value to science lies in

the fact that whenever, in a new experimental situation, a law appears to be broken, it provides an incentive to search for new phenomena or new processes that would remove or explain the apparent discrepancy.

MODEL An artificial construction invented to represent or to simulate the properties, the behaviour, or the relationship between individual parts, of the real object being studied.

model

Examples 1 The structure and functions of the human heart are quite complicated. But for a simple description, quite adequate for an understanding of its main role, you could say that the heart behaves like a pump. Hence in this sense a pump in a central heating system is a model of the heart.

2 Before the age of space travel, no one could actually see that the Earth was round. Yet from many observations it was possible to conclude that it must be. Thus a sphere became a model for the shape of the Earth (more about this later).

3 All grains of ordinary cooking salt have the same shape, namely a cube, even if their size is different. There must be some regularity in the internal structure of all grains, which cannot be seen directly, but can be deduced from chemical and physical experiments. In order to visualize this structure, it is useful to build a three-dimensional model. In this case the model will consist of an array of small cubes and of spherical balls of two different sizes, representing the two chemical constituents, chlorine and sodium. The balls will be arranged alternately at the corners and at the centres of the walls of each cube.

4 Once a student of chemistry gets used to visualizing three-dimensional spatial models of substances, it becomes obvious that such models are too cumbersome. They are, therefore, often replaced by something much simpler, by a combination of letters and various signs. Cooking salt can be represented simply by NaCl or by $\text{Na}^+ \text{Cl}^-$. These letter models convey less information than the three-dimensional cube model, but are quite adequate for many purposes, once their meaning has been agreed and accepted.

5 In a more general sense, if you use the word 'horse' to communicate something about either one particular animal or about the whole species, it is a form of modelling. Similarly the symbol 3 is a model for any situation in which three different objects are present or taken into account. Mathematical expressions and equations are also a form of modelling.

In all these cases, a word, a symbol, a visual image or a formula enable you to communicate some information not about that word or symbol, but about some other object or situation in the real world, which the word or symbol represents.

Comment Notice that in none of the examples above does the term model stand for a scaled-down replica of the real thing. Here, we are not talking about balsa-wood or plastic miniatures of ships or planes.

Although there is usually some form of similarity or correspondence between the model and the thing it represents, they are not identical, nor are they mirror images of each other. The usefulness of models lies in their representing something new, unknown and complicated, by something else, simpler and already known to us.

THEORY A set of very few general statements that correctly describe and explain all experimental observations about the behaviour and properties of a large variety of material objects or systems.

theory

Examples 1 Newton's theory of universal gravitation can be summed up in a single statement about how the attractive force between two bodies depends on their masses* and on the distance between them. Yet this one formulation embraces an endless multiplicity of real individual situations, from falling apples to the motion of planets and satellites.

2 The propagation of radiowaves, light and X-rays through empty space as well as through a variety of materials (glass, water, metals, etc.) can all be summed up in the form of only four mathematical equations, first formulated by Maxwell (electromagnetic wave theory).

* You need not worry at this stage about the exact meaning of the term 'mass'. We shall be dealing with that in Unit 3.

3 Later in the Course you will find examples of other theories, such as, for example:

Mendel's theory of inheritance;

Darwin's theory of evolution by natural selection;

the electronic theory of atomic structure;

plate tectonics, describing the movements of the Earth's crust.

In all cases, a relatively simple and very general formulation, or a set of very few rules, provides a correct insight into an otherwise bewildering multitude of individual variations.

1.4 Summary of the Introduction and Section 1

Although the origins of science lie in man's desire for knowledge, science is a social activity based on and conditioned by practical needs and social pressures. In industrialized societies, the progress of science and its applications strongly influence the way of life. The problems of the use or misuse of science cannot be solved from within science. This puts an obligation on scientists to help the general public to understand and appreciate the advantages as well as the dangers inherent in scientific solutions of current problems.

The scientific method is characterized by a combination of experimentation and reasoning. Specific techniques are developed for obtaining results from experiments and for recording and analysing them. Equally important are the thought processes, such as formulation of hypotheses or scientific models, which ultimately lead to an increasingly better understanding of the world.

2 What shape is the Earth?

For the rest of this Unit you will be asked to consider questions concerning the most basic features of the Earth and its relationship to the Sun and the Moon. You may well be forgiven for feeling cheated, because you already know it all and you will not learn new facts.

But bear with us for a moment. How did you come to know that the Earth is round and that it spins about its axis and orbits around the Sun? More likely than not, you have just been led to believe it, because your parents and your teachers told you it was so from your early days. But can you justify why you believe it? Your eyes tell you that the surface of the Earth is flat, or undulating, depending on where you are, but certainly not that it is spherical. And you cannot possibly have any direct evidence from your senses about the motion of the Earth. What you have accepted is a *model*, worked out by previous generations of scientists and gradually adopted into the pool of general human knowledge.

It is a worthwhile exercise to forget all this knowledge for a moment and try to retrace its derivation from everyday experience. The purpose of this Unit is to guide you through this derivation and to illustrate from this example how different aspects of scientific reasoning work in practice and how theoretical models are constructed, modified or rejected.

2.1 The pancake model

Imagine for a moment that you are living in the very distant past as a member of a tribe whose territory consists of a large and relatively flat area, covered by meadows, lakes and woods and restricted all round by impenetrable forests. Your tribal community supports itself entirely by hunting, fishing and primitive farming.

What sort of a picture could such people have about the place where they live? Surely they would be aware of the Sun and of the fact that it provides warmth for personal comfort, and light that makes wild beasts visible for hunting (or avoiding). They might even notice that the heat and the light from the Sun help plants

to grow (if only because they grow less well in places shielded from it). On the other hand, the Moon and the stars, which keep appearing only when the Sun is gone, have no obvious relevance to everyday life. Even less understandable are some other natural phenomena such as wind, rain, snow, thunderstorms and earthquakes. They do not exhibit any obvious regularities and their effects on the well-being of the tribe are unpredictable, sometimes good, sometimes bad.

It is reasonable to speculate that the scientist (or the 'magician') of the tribe could formulate the following model of the world: The place where the tribe lives (the Earth) is a *flat pancake* of a sort, which is at rest (most of the time anyway, earthquakes excepted), and the Sun is some sort of a glowing disc or a *fireball* that moves repeatedly over the pancake. All other details—such as what happens to the fireball when it disappears, how it gets over to the other side of the pancake, if it is indeed one and the same fireball all the time or a new one every day—would be quite beyond his grasp.

In spite of all its crudity, this most primitive pancake model already has an element of scientific approach in it. It is not just a direct, raw experience, it is an artificial mental image of something that cannot be directly perceived as a whole.

How would this model of the Earth be modified by another tribe who, instead of being land-locked, lived by the seashore or on an island?

Well, their range of direct observations would be wider because they would observe the surface of the water extending as far as they could see and would probably notice regular tides and possibly even their connection with the Moon. They would still regard the Earth as a pancake or a disc, but it would be either surrounded by water or floating on it like a huge boat. They might still regard the Earth as being at rest, because there is no sensation of its motion, not even of its floating on the water. The Sun would be moving around the Earth–water disc, or alternatively emerging from the waters and descending into them. The stars in the skies would be no more than some very distant and unreachable stage-setting, but the Moon could possibly be recognized as some object or mysterious being looking after the motion of the masses of water.

As long as direct observational experience is limited to a small part of the Earth's surface, the pancake model is the most sensible one, indeed perhaps the only reasonable one. There is nothing to suggest otherwise.

2.2 The spherical model

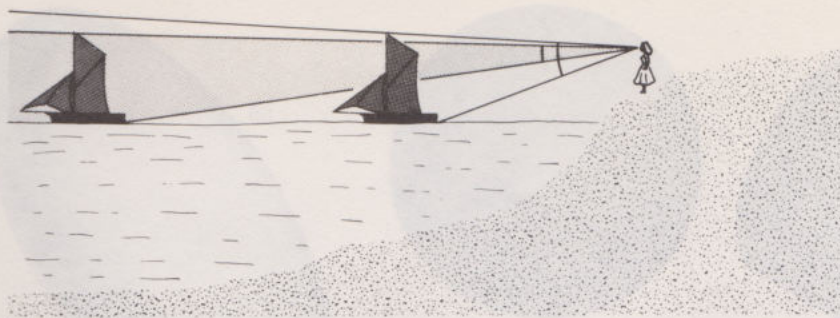
The flat-disc or pancake model of the Earth had to be abandoned only when people were able to collect and compare observations from much larger areas of the Earth's surface. In particular, when they were able to build ships strong enough to travel far into open seas and large enough to be visible from the shore over long distances. This new experience provided two kinds of evidence that *the surface of the ocean is curved and not flat*.

First, a large departing ship appears to be sinking into, and an arriving ship emerging from, the waters. Yet, sailors know that their ships remain on the surface all the time, and they in turn will testify that they saw the harbour and the shore sinking or emerging (Figure 1).

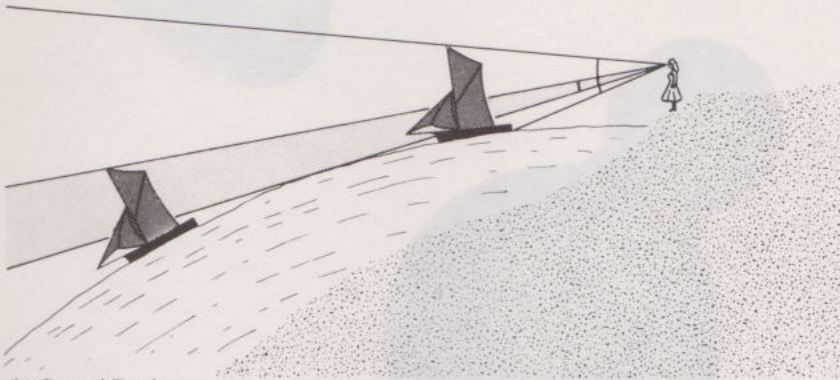
The only possible explanation of this observation is that the surface of the water is not flat*. If the ocean surface is curved, it would seem likely that the surface of the Earth as a whole is curved as well.

Second, the positions of the stars in the skies start changing as a ship travels south or north. The stars on one side of the horizon appear to the voyagers to be attaining higher and higher altitudes, and the stars on the other side appear to be moving lower down or even disappearing altogether. On the return journey these changes are gradually reversed until all is the same again in the home port. It is obvious that these changes are not *real* changes in the skies, because those who do

* By the way, did you notice that this explanation involves the hidden assumption that everybody involved in these observations sees straight or, in other words, that light travels in a straight line. Reasonable enough in this case, but not absolutely true!



(a) Flat Earth

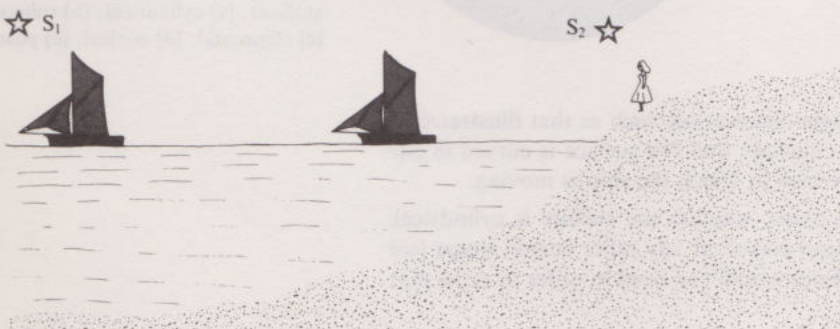


(b) Curved Earth

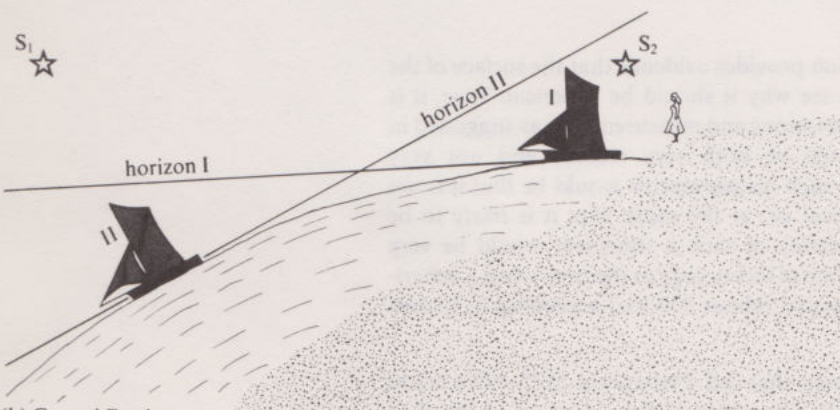
FIGURE 1 Visual evidence that the Earth is not flat.

(a) If the Earth were flat, a departing ship would be seen diminishing, but always complete.

(b) In fact, a departing ship appears to be sinking as it disappears below the observer's horizon.



(a) Flat Earth



(b) Curved Earth

FIGURE 2 The Earth is not flat—from the observation of stars.

(a) If the Earth were flat, both stars S_1 and S_2 would be seen from the ship, no matter how far it travelled.

(b) When the ship moves from I to II, star S_1 moves higher above the horizon and star S_2 disappears.

not travel do not observe them. The changing pattern in the motion of the stars must therefore be due to the *changing position of the observer* in the ship. If the Earth and the ocean surface were essentially flat, this would be impossible. Provided that the distance to the stars is much larger than the range of travel (a very reasonable assumption, supported by the fact that no changes are ever observed in the relative positions of stars within constellations), then all stars would be seen in the same positions from all places on the land or sea. Once again, the only possible explanation of the observed changes lies in accepting that the surface of the ocean is not flat, but curved (see Figure 2).

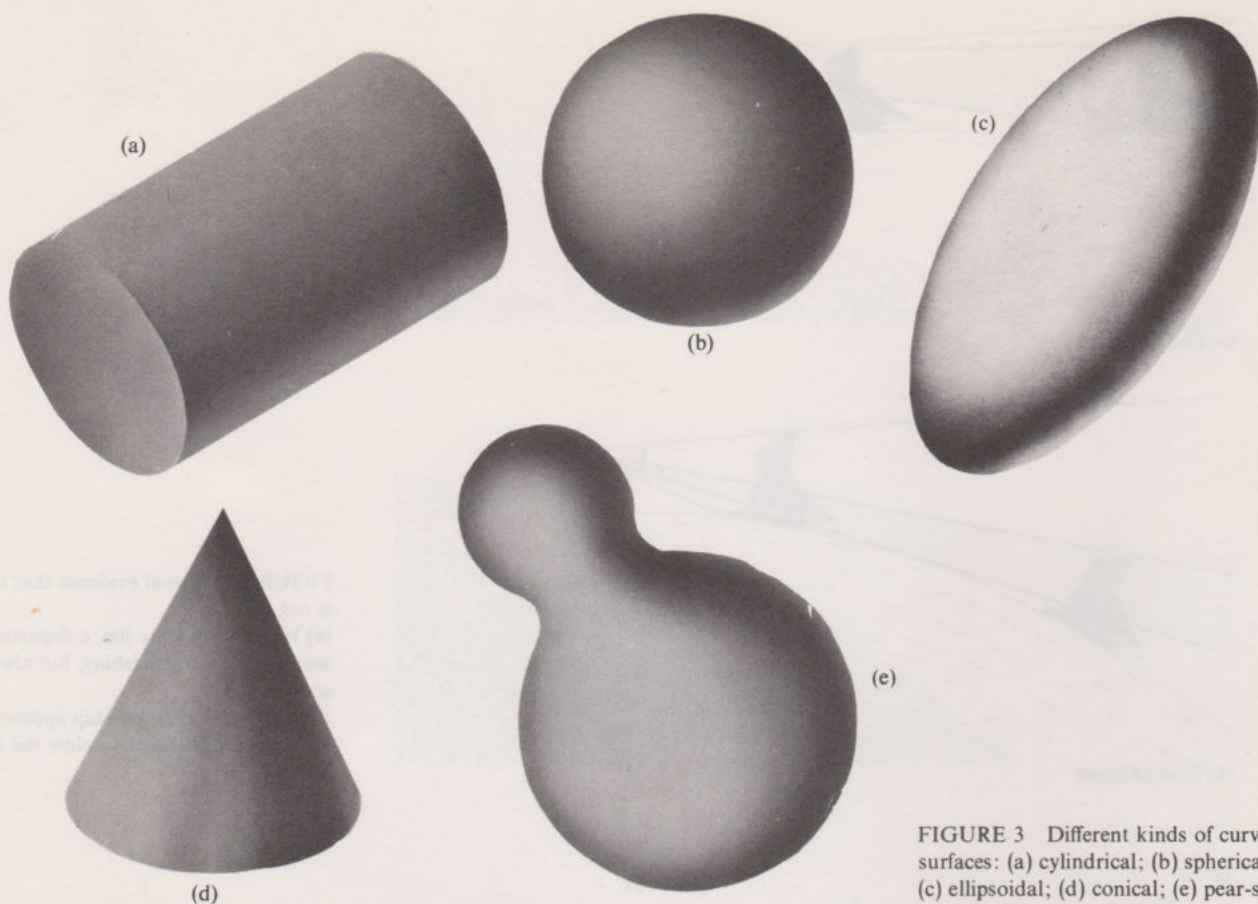


FIGURE 3 Different kinds of curved surfaces: (a) cylindrical; (b) spherical; (c) ellipsoidal; (d) conical; (e) pear-shaped

ITQ 1 On the basis of one single observation, such as that illustrated in Figures 1 and 2, one can only conclude that the surface is curved in *one* direction, namely along the direction in which the ship is moving.

Can you tell, on this evidence alone, whether the surface is cylindrical, spherical, ellipsoidal, pear-shaped or any other curved shape (see Figure 3)? What additional evidence would you need in order to show that the surface is spherical?

Answers to in-text questions (ITQs) are on p. 45.

Thus, although direct visual observation provides evidence that the surface of the ocean is not flat, it is not so easy to see why it should be spherical. True, it is possible in principle to repeat the observations and measurements, as suggested in the answer to ITQ 1, but this would be both very tedious and not very accurate. The best we could get from such measurements would be that it is *not impossible* for the Earth to be spherical or, at the most, that it is *likely* to be spherical. But the accuracy and reliability of such a statement would be very limited, particularly considering the state of technology at the time when a spherical model of the Earth was first suggested (about 500 B.C., according to known historical records).

It is instructive to follow the reasoning that led Pythagoras (572–492 B.C.) to suggest that the Earth *is* spherical. He was aware of the curvature of the then explored part of the Earth. He also attached a great significance to the fact that both the Sun and the Moon were either circular discs or more likely spherical objects (at least the Moon, because of the shape of its phases). Stars in the skies appeared to follow circular paths during the night. In everyday life he observed that of all possible curves a circle looked the most regular and was the most easily drawn, that a circular cross-section was the only useful shape for the wheels of carts and that spherical objects rolled most easily in any direction. Thus he formulated an idea (or principle) that a circle is the most perfect curve and that *a sphere is the most perfect shape* any object in the world can have. And because the Earth to him was undoubtedly something of prime importance and perfection, at least as important and perfect as the Sun or the Moon, it seemed only natural to believe that it *must* be spherical.

This model of a spherical Earth represents a great advance of scientific thinking over the pancake model. First of all, it takes into account the observation that the surface of the ocean (and therefore probably of the whole Earth) is not flat. Second, it attributes to the Earth a shape that is known to be the shape of other important and perfect things. Last, but not least, it offers a very simple solution to the problem of what happens to the Sun after the sunset. There is no need to worry any more about the possibility that it disappears into the ocean and is reborn again in some mysterious way the next morning. If the Earth is a sphere, then all is explained easily by assuming that the Sun (as well as the Moon and the stars) travels in a circle around the Earth.

Although Pythagoras was the first man (according to known records) to propose that the Earth has a spherical shape, it is Ptolemy whose name is connected with the so-called *geocentric model of the Universe*. In about A.D. 150, Ptolemy produced an extensive catalogue of celestial objects and explained all their motions in the skies by assuming that the Earth is a stationary sphere resting at the centre of the whole Universe. (Hence the name geocentric, where the prefix *geo-* comes from the Greek *ge* = Earth.) According to this model, the Sun, the Moon, the stars and the planets all travel around the Earth either in simple circles or in more complicated paths that can nevertheless be explained by combining one main circular motion with additional motions in much smaller circles around the main path (epicycles).

This geocentric model, so attractive in its simplicity, also conformed very nicely with the Christian religious teaching about God's creation of the world and man, and about the special role of the Earth in the Universe. It is not without interest that there was a parallel stream in Greek philosophy (Philolaus and Aristarchus are the names usually connected with it) that regarded the Sun and not the Earth as the centre of the Universe. Although the scientific merits of this alternative model were at least equivalent to the geocentric model on the evidence then available (and we would regard it as preferable), it was rejected by most people on purely general, philosophical grounds, stemming entirely from the sense of self-importance of man and the Earth. And because the Church officially embraced Pythagoras's harmony of the spheres and Ptolemy's geocentric model, the development of science was stifled and hindered for several centuries.

The discussion of the possible shape of the Earth in this Section should have helped you to achieve one of the Objectives of this Unit, namely to distinguish, or to appreciate the difference between the following three aspects of scientific method:

- 1 direct observations;
- 2 assumptions made in interpreting or analysing the observations;
- 3 features of a model simulating, reproducing or explaining these observations.

To check whether you have achieved this Objective, try the first self-assessment question (SAQ 1), which relates to a very different experimental situation.

SAQ 1 Imagine two identical vessels containing equal volumes of two different liquids A and B. Inside both vessels are identical immersion heaters and these are switched on for the same period of time. The temperature of both liquids is measured before and after the heaters are used.

Identify which of the statements from the list below are observations (O), assumptions (A) and features of a model (M) that explain the observations.

- 1 The temperature of both liquids is the same before the heaters are switched on ().
- 2 Heat losses from both vessels are the same ().
- 3 There is no break in the electricity supply to one of the heaters during the heating period ().
- 4 The temperature of liquid B is much higher than that of liquid A when the heaters are switched off ().
- 5 Liquid B consists of lighter particles than liquid A so that the same amount of heat gives them more motion and therefore higher temperature ().

Answers to SAQs are on p. 46.

geocentric

3 The Earth and the Universe—everyday experience and observations

In the previous Section you have been concerned merely with the Earth and with the ways in which ideas about its shape grew from everyday observations. It was quite obvious how the possible models depended on the life-style and natural environment of those making the observations. The relationship between the Earth and other celestial bodies, in particular the Sun and the Moon, has been mentioned only in passing.

In theory, the simplest and most reliable answer to the question of how the Earth relates with the Sun and the Moon would be found by travelling sufficiently far away from all three of them and having a look 'from the outside', as it were. Alas, this is still well beyond human capability and must remain a topic for the science-fiction books and television serials. However, it should be possible to understand this relationship by analysing all the relevant observational evidence and by developing a model for the mutual positions and motions of all three bodies that would reproduce, simulate or account for the observations.

This Section will present a summary of the relevant observational evidence and the next Section will be devoted to the development of a model based on it.

3.1 Days and nights

The regular sequence of days and nights is surely the most common experience shared by all people and indeed by all living creatures on the Earth. It is taken so much for granted that it represents an ideal of certainty, permanence and regularity.

Yet a closer look soon reveals that this eternal sequence does not have a perfectly rigid pattern. To begin with, it is *not the same for the whole Earth*. The Sun rises earlier for an observer in Tokyo than for one in Paris. This can be easily established, and the difference in time accurately measured, thanks to long-distance communications by telephone or radio. Moreover, even an observer who stays put in one place will experience *variations in the relative length of daylight and darkness*. These variations are related to the position of the Sun in the skies. Approximately half-way through the daylight period (noon), the Sun reaches its highest point above the horizon, known as the *culmination point*. This culmination point does not remain the same all the time, and it is common knowledge that days are long when the culmination point is high and short when the Sun culminates low above the horizon. The relationship between the height of culmination and the length of daylight connects the day-night cycle closely with the cycle of seasons. But before going into any further details of this connection, let us emphasize one all-important observation about the day-night cycle. Although there are local variations as well as seasonal variations in the relative length of days and nights, *the time interval between two consecutive culminations of the Sun* remains constant. It is the same for all observers anywhere on the Earth and remains the same throughout the year (apart from some minor variations which need not concern us for the time being). For this reason, the interval between two consecutive culminations of the Sun became one of the first natural units for measuring time and is known as a *solar day*.

culmination

solar day

3.2 The four seasons

When the relative durations of daylight and darkness within each solar day are systematically measured and recorded over a long period of time, a clear pattern emerges that repeats itself regularly. This pattern is reflected in seasonal climatic changes, and there is an obvious relationship between the length of the day, the height of the culmination of the Sun and the amount of light and heat received from the Sun at the place where the observations are being made. Table 1 summarizes these observations, starting from mid-summer.

This pattern of four seasons shows significant differences for different parts of the Earth's surface. Thus when Britain enjoys its summer, Australia has to endure its winter. In fact, the whole pattern is *reversed* for the two parts of the Earth

TABLE 1 The seasonal cycle

Relative length of daylight and darkness	Culmination point of the Sun	Name of the day (date)*	Climatic observation	Name of the season
longest day and shortest night	highest	summer solstice (21 June)	hot	summer
day and night of equal length	average	autumnal equinox (23 Sept.)	mild	autumn
shortest day and longest night	lowest	winter solstice (21 Dec.)	cold	winter
day and night of equal length	average	vernal equinox (21 March)	mild	spring

separated by the Equator (northern hemisphere, southern hemisphere). Furthermore, the *intensity* of seasonal changes *varies with location*. Around the Equator, seasonal changes are hardly noticeable, but in the arctic regions they are so great that they can even temporarily obliterate the usual day–night cycle. There is a period during which an arctic observer sees the Sun moving above the horizon and never setting below it (polar day in the arctic summer) and another period during the arctic winter when the Sun never emerges above the horizon (polar night).

However, in spite of all these local variations, there is one common feature. For any place on the Earth, the time interval between two identical observations (for example, two consecutive summer solstices) is the same. Thus there is some underlying regularity reflected in the *constant length of one complete seasonal cycle*, whatever its local details.

Incidentally, in order to avoid any confusion or misunderstanding that might arise from the fact that many observations are different at different parts of the Earth’s surface, let us agree that from now on any observations described or explained will be those that can be made in Britain or in places of similar latitude within the northern hemisphere, unless specifically stated otherwise.

3.3 The Sun and the Moon

The Sun and the Moon are the two largest objects visible in the skies, in fact the only two objects that appear to the unaided eye as large circular discs. All other celestial bodies visible at night appear just as small points of different brightness.

The first interesting observation to make is the fact that the Moon, when seen full, appears to be of about the same size as the Sun. But you know from everyday experience that the *apparent size* of an object does not tell you anything about its *real size*, unless you also know the *distance* of that object from you. A matchstick held at arm’s length appears longer than the mast of a television transmitter a few miles away! At this stage we are not concerned about the real sizes of the Sun and the Moon, or about measuring the distances to them. All we need is the observation that *the apparent sizes of the Sun and the Moon remain constant in time***. This means that whatever their distances from the Earth, they cannot be changing to any great extent.

The Sun is the source of all the light and nearly all of the heat that reaches the surface of the Earth. (Some of the heat comes to the surface from within the deep

* The dates are those for Britain and other places in the northern hemisphere (see the text for further details).

** This is certainly true within the accuracy of observations made by unaided eyes or with the help of small telescopes. The fact that the Sun sometimes *seems* bigger when it is very low above the horizon has nothing to do with its distance. This effect is explained by the passage of light through thick layers of dense atmosphere.

interior of the Earth, as you will find out in Units 6 and 7.) The Moon, by contrast, has much lower brightness and does not provide any heat. It can be seen most clearly during the night, although it is frequently above the horizon during the day. The most striking feature of its appearance is the fact that, unlike the Sun, the Moon is not always seen as a full circular disc. It undergoes a cycle known as *lunar phases*, as shown in Figure 4. These changes of shape correspond to the changes in the time of day or night during which the Moon can be seen above the horizon (provided it is not obscured either by clouds or by bright sunshine). The whole cycle from one new moon to the next is spread over approximately 28 day–night cycles.

lunar phases

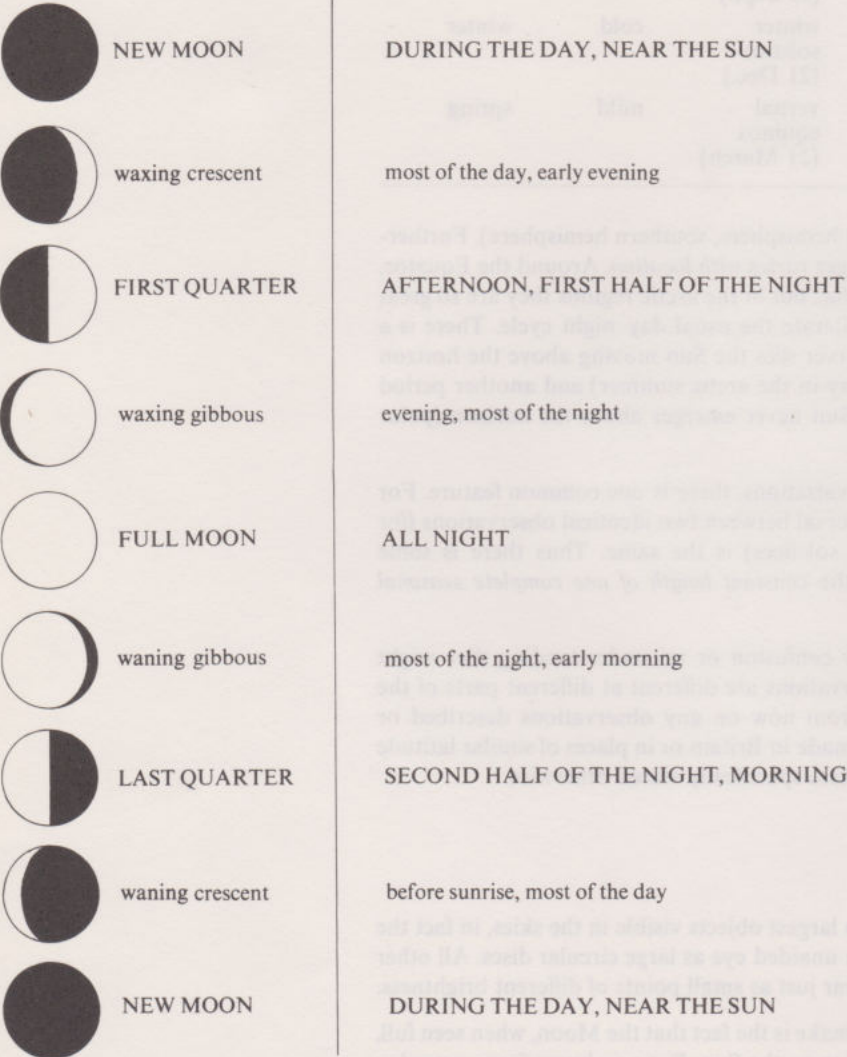


FIGURE 4 Phases of the Moon and its visibility above the horizon.

Another interesting characteristic of the Moon is the appearance of the *darker areas* seen on its surface. The shape of these features (the ‘Man in the Moon’) does not show any appreciable change with time. More importantly, their relative position on the face of the Moon also appears to be constant. They temporarily disappear as one part of the Moon progressively darkens, but they reappear in the same places when that part of the Moon brightens up again. It is as if the Moon were taking special care to show *the same face* to the Earth at all times.

3.4 The stars and the planets

During the night, stars appear to be moving across the skies. Closer observation reveals that in our part of the world there is one particular star, known as the Pole Star or Northern Star, or Polaris, that does not seem to be moving at all. For this reason, its position in the skies has been used through the ages as a reference point for navigation.

Pole Star

Although some of the stars appear to be moving faster than others, there is a fascinating degree of coordination in their motions. To begin with, each individual star travels in a *circle* with respect to the Pole Star. Furthermore, stars remain grouped at all times in the same relative configurations, known as constellations (*stella* = star). These constellations are very stable over long periods of time. Comparing the present situation with the records made by ancient astronomers, there are only very small changes in the shape of some constellations over hundreds and thousands of years.

By contrast with this relatively steady and highly regular pattern of the stars, there are a small number of starlike bright objects that appear to move across the skies without keeping any permanent relationship to any of the constellations. Since they appeared to be 'stars on the loose', so to speak, the ancient Greeks named them *planets*, meaning wandering stars. There are altogether eight such planets, although not all of them are visible at the same time and some not at all without the help of powerful telescopes.

The most unusual feature in the behaviour of some planets is the *shape of their paths* with respect to the stars. If you were to plot, night after night, the relative position of a planet such as Mars or Jupiter with respect to a chosen set of stars or a constellation, the path could look something like Figure 5. This is nothing like a segment of a circle! These loops, during which a planet appears to be turning back for a while, are accordingly called backward or *retrograde loops*. The absence of any obvious reason for such odd behaviour had always been the weakest point of the geocentric model of the Universe and led to its eventual downfall. However, in spite of this somewhat untidy progression across the skies, even the planets behave in a perfectly predictable way. Medieval astronomers were quite capable of forecasting when each planet would next appear, and court astrologers made a decent living out of predicting future events important to their masters from the coincidence of the planets with some individual stars in prominent constellations.



FIGURE 5 A retrograde loop in the path of a planet with respect to the stars, as seen from the Earth (not to scale).

3.5 The periodicity of events

In spite of all their local variations, all the observations discussed in this Section indicate that there is some basic underlying *regularity*, some intrinsic order in the world as a whole, that is manifested by the apparent inevitability of many events. Thus night always follows day, spring follows winter and the first half of the Moon follows the new Moon. If you choose one particular event or situation, let us say (for argument's sake) the full Moon, you can be certain that after a sequence of due changes this particular event or situation will be exactly repeated again. Moreover, the whole sequence of events in between the two identical situations will be exactly repeated. It is customary to call any process which consists of a regular repetition of one and the same sequence of events a *periodic process*. The time it takes to complete the unique sequence just once is called the *period* of the process.

Perhaps the simplest examples of periodic processes in everyday life are the rotation of a turntable, the swinging of a pendulum of a grandfather clock, and the swings and merry-go-rounds in the playground. In order to gain a better feeling for periodic processes (and also to take a break from reading), try one or both of the following two simple Home Experiments.

planet

retrograde loop

periodic process

period

Home Experiment 1 Rotating turntable

If you have a working gramophone of any kind, cheap or hi-fi, set it for playing the standard size longplaying records. The position is usually identified by a number $33\frac{1}{3}$ or just 33.

Fix a removable mark of some kind (a small sticker, a piece of sellotape or a chalk dot) at one point near the edge of the turntable. Place a similar mark somewhere on the base (plinth) of the gramophone so that you can tell when the two marks are in line (when looking towards the central pivot of the turntable). Start the gramophone and try to measure (at least approximately) how long it takes the gramophone turntable to go through 10 complete turns and then how long it takes for 20 turns. If you use the stop-watch from the Home Experiment Kit, this task should be very simple. But even with an ordinary watch with a second dial it should be possible to get reasonably accurate timings (particularly if you can persuade somebody to help you either by indicating the start of the first and the end of the last turn, or by taking the readings on the watch while you count the turns).

ITQ 2 What is the period of rotation of your turntable? Would there be any advantage in measuring the time over more turns, say 100?

Home Experiment 2 Pendulum

Take a piece of thin string about 1 metre long and make a simple pendulum by tying some small, compact object to one end—a normal-sized key would do. Place a watch with a seconds-hand in front of you so that you can see your pendulum and the watch at the same time. (Alternatively you can, of course, use a stop-watch in one hand while holding the pendulum with the other hand.) Hold the free end of the string, or better still tie it up to a hook or any other suitable support. Count how many times within 10 seconds your pendulum has gone through the complete sequence of one swing. Or, alternatively, measure the time it takes the pendulum to complete 5 or 10 swings. Try to answer the following questions.

ITQ 3 Does it matter whether you count as one swing the sequence of motion from one extreme position to the opposite extreme and back, or the sequence starting from the vertical position to one extreme through to the opposite extreme and back to vertical?

ITQ 4 How does the number of swings completed in 10 seconds (or the time taken to complete 5 or 10 swings) change when you shorten the length of the pendulum by holding or suspending the string at a point nearer to the swinging object?

ITQ 5 Can you find, by trial and error, the lengths at which the pendulum will complete 5, 8 and 10 swings within approximately 10 seconds?

ITQ 6 What are the periods of the swinging for the three cases described in ITQ 5?

Now back to the main story again. Note that the definition of the period of a periodic process *assumes* that it is possible to measure time. However, the scientific concept of time and the techniques of time measurement are themselves firmly based on the periodicity of some natural processes. Thus one of the first units of time was called a *solar day* and was defined as the interval from one culmination of the Sun to the next. Similarly, one could define a *lunar month* as the time between two consecutive full-moon phases, and a *solar year* as the time between two consecutive summer solstices. These are perfectly adequate units for everyday use. But when it comes to the need for high accuracy they are not so good. It is rather tricky to establish when *exactly* the Sun reaches its culmination point or when exactly the Moon is full. Also, when one compares very carefully two solar days at different times of the year they are not absolutely identical; there are small, but measurable, differences. For more accurate timekeeping, present-day scientists must look to other processes whose periodicity is more reliable. There will be more about this in the next Unit.

3.6 Summary of Section 3

The periodic cycle of days and nights is clearly determined by the relative motion of the Sun and the Earth. The precise details of this cycle seem to vary, depending on where on the Earth's surface the observations are made. There are also longer term, seasonal changes in the relative length of daylight and darkness within one solar day. These are related to the culmination point of the Sun and also depend on the place of observation.

The Sun and Moon are of the same apparent size but their real sizes depend on their distances from the Earth. Their distances (as yet unknown in this Unit) do not change with time to any significant extent (otherwise changes of their apparent sizes would be observed). The Moon exhibits a periodic cycle of lunar phases and has some apparently stable structural features on its surface. It appears to be showing the Earth the same face at all times.

The stars in the skies appear to move in circles around one fixed point (the Pole Star for Britain and Europe). Their rotation is synchronized so that their relative positions remain the same (constellations). Against the background of constellations, the planets (e.g. Mars, Jupiter) seem to follow somewhat strange paths, with retrograde loops.

All astronomical observations show regular periodicity, a fact which enables predictions to be made even without any understanding of the system of the Universe. Periodic processes serve as a means for measuring time.

The aim of this Section is to summarize observational evidence that can be used for the construction of a model describing the relationship of the Earth to the Sun and the Moon. In addition, you should have gained some understanding of periodic processes and have had your first taste of interpreting the results of simple observations and experiments. You will have achieved this Objective if you have carried out the experiments with the turntable and with the home-made pendulum.

4 The Earth and the Universe—building a model

All the observations summarized in the previous Section indicate that the Universe is not a static system. *There is undoubtedly motion*; but what is moving and how?

In most everyday situations, when you move (or are moved) you have a *sensation of motion*. But if you sit tight on a piece of rock, or anything else firmly attached to the surface of the Earth, there is no sensation that the Earth as a whole is moving. It was, therefore, only natural for most of our ancestors to believe that the Earth is stationary and that everything else is moving around it.

But is it reasonable to rely on human senses for the detection of motion? How sensitive, or reliable is man's sensation of motion? Consider the following imaginary situations:

1 You are travelling in a modern inter-city train on a perfect track, that does not cause any bumps or shakes. You have just woken up from a short nap, and the first thing you see through the window is another train, just like yours, passing by. Do you think that you would be able to distinguish instantly—and without reference to other observations such as the landscape, station buildings or telephone poles—between the following possibilities:

- your train has stopped at a station, through which the other train is passing;
- your train is moving past another train that has stopped at a station;
- both trains are moving, in opposite directions;
- both trains are moving in the same direction, but one of them is travelling very much faster?

2 You are dressed in a diving suit and placed in a very deep cylindrical vessel, half full of water. The weight of your suit is just sufficient to pull you below the surface. You are not trying to swim or move in any way. Through the transparent slits in the helmet of your suit you can see only water and the uniform, unmarked wall of the vessel.

Do you think that you would be able to distinguish, on the basis of your sensations only, between the following situations:

- (a) the water-level is steady and you remain suspended in the same place;
- (b) the water-level is steady, but you continue to sink slowly;
- (c) the water-level is rising, but you remain at the same place in the vessel;
- (d) the water-level is rising (or falling) and you are rising (or falling) at the same rate (keeping constant depth below the water surface)?

3 You have entered a cabin of a *perfect* lift on the thirtieth floor of a sixty-floor skyscraper. You have not checked the light signals and somehow you did not register the initial jerk as the lift started. Can you be absolutely sure at any moment whether you are travelling up or down? When will you be sure and what would you feel?

Well, the long and the short of all this is that human senses cannot always distinguish between rest and motion. The only situations in which you have a very clear sensation of motion are those in which *the state of motion is changing*. Thus the speeding up of the lift as it starts to go up makes you feel pressed against the floor and the slowing down before it reaches the upper floor makes you feel floating upwards. The feeling is caused by the relative motion of some internal organs (the stomach in particular) with respect to the more rigid frame of the body. The sensitivity is slightly greater for up and down changes than for sideways motions, but it is quite generally true that *a steady motion*, in the same direction and at the same speed, is undetectable. And let us say here and now that this is not because of any particular inadequacy of human senses. There is no experiment and no instrument that could detect *steady* motion of any system *from within that system*. This is one of the most fundamental features of the world, verified by countless observations and test experiments.

But what about motion in a circle, such as on a rotating turntable or a merry-go-round? This is not a steady motion, even if the speed of rotation is constant. The *direction* of motion is continuously changing and you can *feel* the motion when you sit on a rotating merry-go-round. But even here, human senses are not only fallible but also very adaptable. It is well known that after a sufficiently long exposure to some more or less constant influence—whether it is smell, noise or pressure—most people become used to it to such an extent that they completely *lose any awareness* of it. It is not very difficult to imagine that if somebody spent most of his life in the seat of a smoothly and steadily rotating merry-go-round, without any reference to the world outside it, he would not have any sensation that he was rotating. Although such motion is always detectable by suitably designed experiments, it is not necessarily always registered by human senses and the human brain.

Thus when it comes to answering the question of how the Earth relates to the rest of the Universe, there is *no justification for assuming that the Earth itself is not moving*—it may or may not be.

4.1 The Earth and the Sun

In order to understand the place of the Earth in the Universe, it is necessary first to understand its relationship to the Sun. The point has already been made (in Section 3) that this relationship cannot be observed directly, but can be represented by a suitably chosen model.

It is reasonable (in view of Section 2) to start by representing the two bodies by *two spheres*, one of which radiates heat and light from its whole surface in equal amounts in all directions (the Sun). Further developments of the model will consist of choosing *appropriate relative motions* of the two spheres that would *reproduce the observations* described in the previous Section. (Note that further details of the model, such as the actual sizes and separations of the two bodies, can be left until Unit 2.)

So, what kinds of possible relative motions should you consider for the two spheres? If you recall the observation that both the day–night cycle as well as the cycle of the seasons are (in spite of all their local variations) essentially periodic processes, it is obvious that the relative motions of the two bodies must be *periodic*, that is, whichever of the two bodies is moving and however it moves,

there can be only a limited sequence of possible different configurations of the two bodies and this sequence of configurations is regularly repeated. Furthermore, the observation that the apparent size of the Sun, as seen from the Earth, remains the same, can only mean that the two spheres must always be at the same separation.

There is only one motion that satisfies both of these conditions, namely, that it is periodic and keeps the separation between the two bodies constant. Surely you know what it is? It is motion in a circle*.

Thus, by using two observations, you already have one necessary feature of any model for the Sun–Earth relationship:

OBSERVATIONS	FEATURE OF THE MODEL
1 Periodic cycles 2 Constant apparent size of the Sun	any relative motion is circular

4.1.1 Two kinds of circular motion

When you measured the period of rotation of your gramophone turntable (Home Experiment 1), you did so by placing a mark near the edge of the turntable disc and by following the motion of this mark with respect to a fixed line determined by the central spindle and by another mark, firmly attached to the stationary base of the gramophone. If you were to compare the motion of the central spindle with the motion of the mark near the edge, how would you describe the difference?

Well, it is quite obvious that there is a difference, although both the spindle and the mark are in circular motion. The immediately obvious difference is that the spindle stays put at the same place in the centre, whereas the mark travels in circles around it. But if you look at the spindle more closely, you will notice that individual points on its surface also travel in circles. Now try to visualize a line going through the centre of the circular cross-section of the spindle and parallel to its length. The points on this line do not move at all and this line represents an axis around which the rest of the spindle revolves. This kind of motion, in which there is a fixed line *within* the body around which the rest of the body is turning, is called *spin* (or spinning motion) and the fixed line of stationary points is known as the *axis of spin*.

spin
axis of spin

Can you think of a few more examples of motion from your everyday experience that could be described as spin?

Drive shafts in cars, tops and gyroscopes, spin-dryers, drilling bits in power tools, pirouetting figure skaters, etc.

The motion of the marker on the gramophone turntable does not have any such fixed reference line within the marker itself. It is a motion along a closed path of circular shape, but the centre of the circle is *outside* the marker. This type of motion is known as *orbital motion*.

orbital motion

Note that it is accepted practice to use the term orbital motion also for motion that is not circular, provided that the path is closed and its shape fixed, so that the moving body travels repeatedly in the same way during each complete turn. The most common non-circular orbital path is an ellipse (more about this in Unit 2).

Can you think of a few examples of orbital motion?

Teeth on a circular saw, the valve on a bicycle wheel, long-distance runners in a stadium, horses on a race track, fan belts, seats on a merry-go-round, trains on the Circle Line in London, etc.

Returning to our model of the two spheres representing the Sun and the Earth, there is a large number of possible combinations of different motions. Either of the two bodies can orbit around the other one, and either one of them may or may

* Strictly speaking, the motion of a pendulum bob also satisfies both of these conditions. But a pendulum bob periodically reverses its direction of motion, whereas the Sun always moves in one direction.

not spin. This variety of options can be reduced by taking into account the appearance of the Sun.

Does the Sun show any periodic changes of its shape or of its brightness from which one could conclude that it spins? No such changes have been noticed in everyday observations. Large telescopes reveal some very small spots of lower brightness on the Sun's surface (sunspots). The motion of these spots indicates that the Sun could be spinning with a period of about a month but, in spite of this, the overall amount of light and heat emitted from the Sun's surface remains the same in all directions and at all times (within our lifespan, anyway). It is therefore reasonable to leave the spin of the Sun out of future consideration, because it does not make any difference to Earthbound observations.

This leaves only four different options for the motions of the Sun and the Earth (Figure 6):

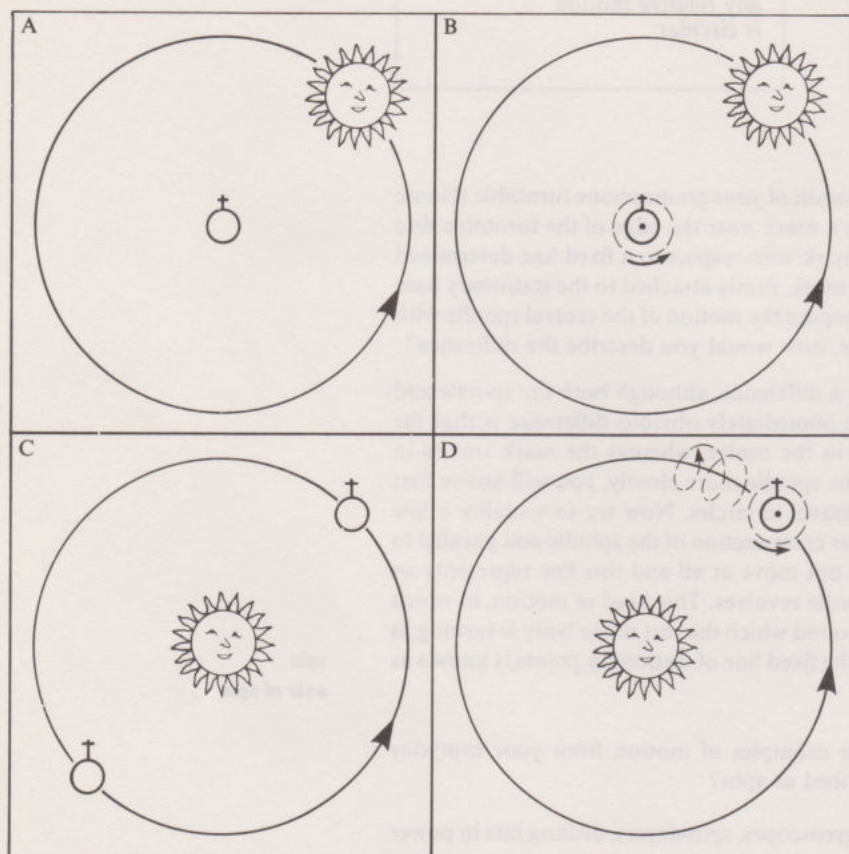


FIGURE 6 Possible options for the model of the Sun-Earth relationship. The short cross on the smaller circle represents an observer on the Earth; the spiral in D indicates the effect of the combined (orbital + spin) motion. The dot in B and D indicates the Earth's axis of spin.

- A The Earth is stationary* and does not spin: the Sun orbits around the Earth.
- B The Earth is stationary and spins; the Sun orbits around the Earth
- C The Sun is stationary; the Earth orbits around the Sun and does not spin
- D The Sun is stationary; the Earth orbits around the Sun and spins at the same time.

4.1.2 What causes the day-night cycle?

Leaving aside everything else for the moment, *option A* could account for the day-night cycle, provided the Sun could complete one full orbital cycle in one solar day. This would lead to very large, perhaps even impossibly large, velocities for the Sun, if its distance from the Earth is very large. Although this is a potential problem, it would not on its own justify the rejection of option A. A far more serious objection to A is that having used the orbit of the Sun to explain the day-night cycle, there is no other motion left to account for the periodic seasonal cycle.

A very similar argument can be made against *option C*. Once again, a day-night cycle could be accounted for by the Earth completing one circle in one solar day,

* Note that *stationary* in this context does not mean *motionless*. It means fixed position in space, but spin is allowed.

but there is no other motion left to explain any other periodic observations (seasons).

Options B and D have the obvious advantage that two different periodic motions are available and therefore more than one periodic observation can be explained.

But perhaps there might be some other explanation for the long-term seasonal cycle, not necessarily dependent on the spin or orbital motion? It does not seem likely, but in order to reject options A and C convincingly, it would be nice to have some *direct evidence* that they are wrong.

Identify the one *assumption* about the Earth which is common to options A and C. What kind of an experiment would definitely eliminate both of these options?

The one common assumption is that the Earth does not spin. Therefore, any experiment that shows that the Earth does spin, eliminates both options A and C.

Well, is there any way to check whether the Earth spins or not?

Home Experiment 3 Another pendulum experiment

Make yourself another pendulum such as that used for Experiment 2. You can even use the same one, provided the length is at least 1 metre (the maximum length should not exceed your height). The pendulum bob should not be too light, so use a good-sized key, a pair of scissors or some such object.

Find a *fixed line* on your floor (using the pattern of your carpet, a row of tiles or something similar) and start the pendulum swinging along this line. Try to hold the pendulum in front of you *in the same position* above the chosen reference line while taking a step to one side. Imagine that your fingers holding the pendulum are at the centre of a circle, and move your body gradually, step by step, around that circle. During this procedure *the orientation of your arm* holding the pendulum will have changed through a full circle.

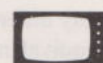
ITQ 7 Did you observe any change in the direction in which the pendulum was swinging? How would you formulate the result of your experiment?

Indeed it is possible to demonstrate that *any freely suspended* pendulum keeps its initial plane of swing fixed in space* and independent of any motion of the point of suspension. You can check this, if you feel like it, in such situations as in a car or in a bus negotiating a bend or even on a rotating merry-go-round.

Does this suggest to you a possible experimental test that would show whether the Earth is spinning or not?

All you would have to do is to construct a pendulum sufficiently long, and suspended with so little friction that it could go on swinging for several hours, once started. You would draw a reference line on the surface of the Earth, indicating the initial plane of swing and then you would just sit and wait. If the Earth is motionless, the pendulum should never deviate from this line. But what if the Earth, carrying the line, spins underneath the pendulum? After a sufficiently long time there would be an obvious difference between the reference line and the plane of swing.

A simple instrument, known as a *Foucault pendulum*, enables us to reject the options A and C because it shows that *the Earth does spin*. You will see a demonstration of the Foucault pendulum in the TV programme associated with this Unit (TV 01).



* By 'freely suspended' we mean that the motion of the bob is not restricted by any *rigid* coupling to the point of suspension. A long, thin string has very little restraining effect even if it is held fixed or tied up to a hook. But if the bob were fitted to a solid rod, then some special suspension would have to be designed to enable the rod to swing without friction in any direction.

In addition to rejecting options A and C, the Foucault pendulum also helps to clarify one important detail in options B and D. In these options there are two periodic motions—the spin of the Earth and the orbital motion of either the Sun (B) or the Earth (D), that can be connected with two periodic observations, the day–night cycle and the seasonal cycle. It may seem *intuitively* more reasonable to connect the spin of the Earth with the shorter of the two cycles, but it is the outcome of the Foucault pendulum experiment that provides a firm answer. Even without any accurate measurements, it is obvious from the time it takes for the plane of swing to deviate from the reference line on the Earth’s surface that the spin of the Earth accounts for the day–night cycle rather than for the seasonal cycle. In fact, a Foucault pendulum suspended exactly above the North Pole would show that *one turn of spin of the Earth takes exactly one solar day*. (In Britain it takes about 30 hours for the reference line to complete one full turn with reference to the plane of swing of a Foucault pendulum. The difference is due to Britain’s distance from the pole.)

Before taking the next step in our model-building exercise, let us sum up our progress so far.

OBSERVATIONS AND EXPERIMENTS	FEATURES OF THE MODEL
1 Periodic cycles (day–night, seasons) 2 Constant apparent size of the Sun	only circular motions
3 Constant brightness and appearance of the Sun	spin of the Sun non-existent or unimportant
4 Day–night cycle 5 Foucault pendulum	the Earth spins with a period of one solar day

4.1.3 What could explain the seasonal cycle and its local variations?

In the previous Section, the spin of the Earth was firmly linked with the day–night cycle. It follows that the second periodic observation—the cycle of the seasons—could be connected only with the orbital motion. You might expect that either the Sun orbits around the Earth (option B) or the Earth orbits around the Sun (option D) with exactly the same period as that observed for a complete cycle of the four seasons—one solar year.

But there is one major snag. Can you see what it is?

What is the shape of the orbit (on all the evidence so far)? Does this shape tie up with the sequence of seasonal changes?

The orbit is circular (evidence: constant apparent size of the Sun). But if the two bodies are always at a constant separation, how can the amount of light and heat received from the Sun vary so much from one season to another?

Your everyday experience tells you that the nearer you stand to a fire, the more light and heat reaches you. Thus it seems reasonable to have a critical look at the conclusion reached earlier about the circular orbits. Perhaps there are some changes in the Earth–Sun separation after all? Perhaps it is just possible that these changes are large enough to explain the variations in the amount of light and heat, and yet small enough not to change noticeably the apparent size of the Sun?

Figure 7 illustrates two possible modifications that one could introduce into the relative motion of the two bodies. Note that in both cases the axis of spin of the Earth is assumed to be perpendicular to the plane of the orbit (plane of the paper).

Would it make any difference if the two bodies in Figure 7 changed places? (This would be equivalent to changing from option D, as shown, to option B with the Earth inside the Sun’s orbit.)

No, since the modifications in distance would remain exactly the same.

ITQ 8 Follow the progress of the Earth through the arrowed positions in Figures 7a and 7b and identify what kind of a season you would expect the Earth to experience at each of them.

The Foucault pendulum

The line between the point of suspension and the bob of a stationary pendulum always points towards the centre of the Earth. (The reason for this will become clear in Unit 3.) For a pendulum suspended over the pole, the line of suspension *coincides* with the axis of spin of the Earth. This is why the rate of deviation between the initial reference line and the plane of swing of a Foucault pendulum at the pole measures *directly* the rate at which the Earth is turning about its axis of spin. Above the equator, on the other hand, the line of suspension of the pendulum is *perpendicular* to the Earth’s axis of spin and the Foucault pendulum would not show any deviation from the initial reference line. In Britain, the rate of deviation is slower than at the pole because the line of suspension is at an angle of about 35° to the axis of the Earth’s spin.

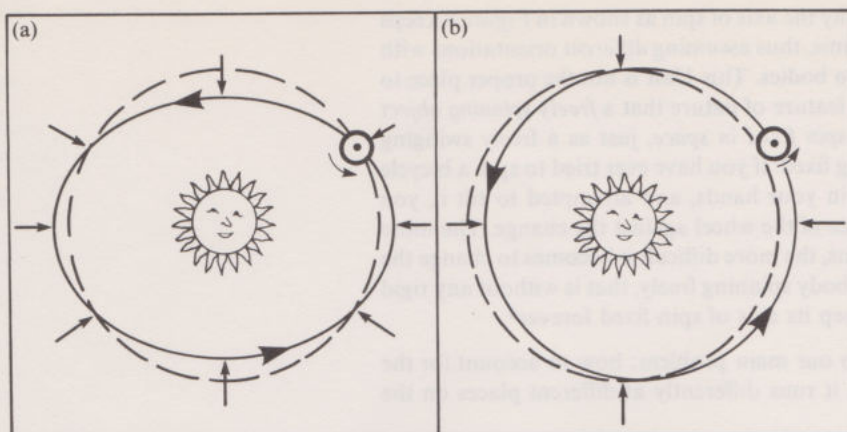


FIGURE 7 An attempt to explain the seasons;
(a) by modification of the orbit; (b) by displacement of the central body.

So far so good. But what about the fact that different parts of the Earth experience different seasons at the same time?

There is no way that this can be explained by modifications to the orbit such as those in Figure 7. Indeed, we seem to have reached a complete impasse. On the one hand, some evidence suggests that the orbit ought to be circular, or at least very nearly so; on the other hand, other evidence seems to indicate that *some parts* of the Earth are nearer to the Sun than others. Impossible?

Well, not quite. There is still one important aspect in the relative configuration of the two bodies that has not been taken into account properly. You probably know what it is, or can easily guess.

It is the *relative orientation of the axis of spin to the plane of the orbit*.

In all previous discussions, and particularly in Figures 6 and 7, the axis of the spin of the Earth was *assumed to be perpendicular to the plane of the orbit* (whether of the Earth or of the Sun). Perhaps this assumption was entirely wrong? What if the axis of spin is in fact oriented so that it lies *within the plane* of the orbit? Would it make any difference?

Well, have a look at Figure 8 and consider what an observer in Britain (indicated) would experience, as the Earth spins about an axis lying in the plane of the orbit (= plane of the paper) and moves through indicated positions on the orbit.

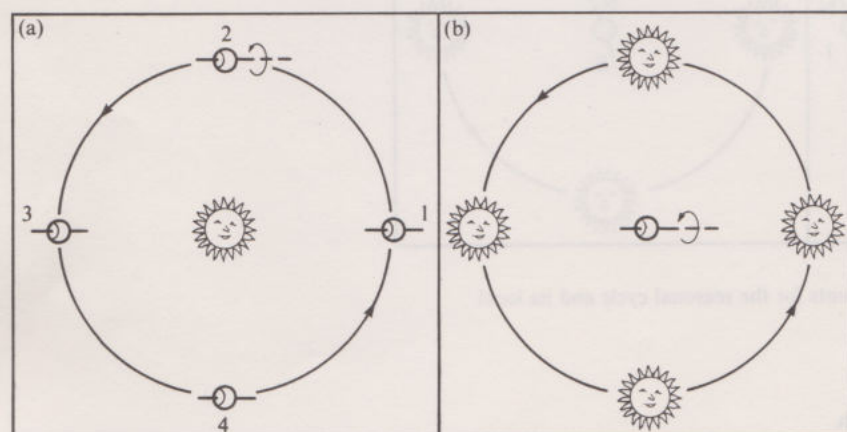


FIGURE 8 Can the axis of spin lie in the orbital plane?
(a) The Earth orbiting the Sun. (b) the Sun orbiting the Earth.
The segment on the left in the Earth's circle indicates northern hemisphere.

ITQ 9 Formulate your own brief summary of this experience.

ITQ 10 Compare Figure 8a with 8b, and identify in 8b the situations in which the observations for a British observer would be identical with those in the numbered positions in 8a. Is there any observation in alternative (a) that is not exactly reproduced in (b)?

Incidentally, you may well wonder why the axis of spin as shown in Figure 8 keeps the same orientation in space all the time, thus assuming different orientations with respect to the line connecting the two bodies. This Unit is not the proper place to discuss any details, but it is a basic feature of nature that a *freely spinning object* keeps the orientation of its *axis of spin fixed in space*, just as a freely swinging pendulum keeps its plane of swinging fixed. If you have ever tried to spin a bicycle wheel on its axle, holding the axle in your hands, and attempted to tilt it, you would have experienced the resistance of the wheel against the change. The more massive the body, and the faster it spins, the more difficult it becomes to change the direction of its axis of spin. Hence a body spinning freely, that is without any rigid coupling to another body, would keep its axis of spin fixed forever*.

After this digression, let us return to our main problem: how to account for the seasonal cycle and for the fact that it runs differently at different places on the Earth.

You have seen earlier that adjustments of orbits did not work (Figure 7). Changing the axis of spin from a direction perpendicular to the plane of the orbit to a direction parallel to it did not work either (Figure 8). But it should have reminded you that there are places on the Earth where, for a certain part of the year, the Sun never rises or never sets. There are only two such areas, they are situated at opposite parts of the Earth and their experience of polar days and polar nights is complementary. Since the spinning of the Earth as a whole continues regularly (as witnessed by the regular day–night cycle at all other parts of the surface), the only possible explanation of this effect could be that the axis of spin is neither perpendicular to, nor does it lie in the plane of, the orbit. It must be *tilted* at an angle *somewhere nearer 90° than 0°* (at 90° there would be no polar days anywhere, at 0° they would be experienced over the whole hemispheres).

Later on, from another independent piece of evidence, you should be able to obtain a confirmation of this conclusion and a better quantitative estimate for the angle of the tilt. In the meantime, convince yourself, by studying Figure 9, that such a *tilted axis of spin can indeed account for the existence of seasons as well as for their local variations*.

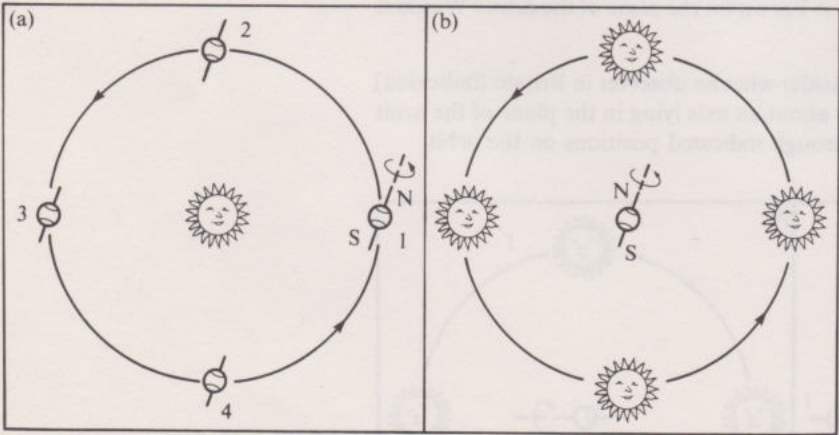


FIGURE 9 The tilted axis of spin accounts for the seasonal cycle and its local variations.

(a) The Earth orbiting.

(b) The Sun orbiting.

N The northern hemisphere of the Earth.

S The southern hemisphere of the Earth.

By now you should have made some progress towards achieving another Objective of this Unit, namely to develop the ability to correlate observations to individual features of a model that can account for them. In order to check your achievement of this Objective, try the following self-assessment questions.

* This is why gyroscopes can measure the tilting of ships, aeroplanes and spacecraft.

SAQ 2 Using a similar line of argument to that which you have used in ITQs 8, 9 and 10, derive from Figure 9a, which season would be experienced by an observer in the northern hemisphere (N) and by one in the southern hemisphere (S) as the relative position of the Earth and the Sun changes from 1 to 4. Fill in your results in the Table below.

Hemisphere	Configuration			
	1	2	3	4
north				
south				

SAQ 3 Compare Figure 9b and Figure 9a and identify (by the same numbers) the situation in which both N and S observers will experience the same seasons as they do in the corresponding situation in Figure 9a.

SAQ 4 Complete the following intermediate summary of the model by including the result of Section 4.1.3.

OBSERVATIONS AND EXPERIMENTS	FEATURES OF THE MODEL
1 Periodic cycles (day–night, seasons) 2 Constant apparent size of the Sun	circular orbits
3 Constant brightness and appearance of the Sun	spin of the Sun non-existent or unimportant
4 Day–night cycle 5 Foucault pendulum	the Earth spins with a period of one solar day
6 Seasonal cycle	
7 Local variations of the seasonal cycle	

4.1.4 Which of the two bodies is orbiting—the Sun or the Earth?

So far it has not been possible to resolve this question, since both options B and D (Figure 6) gave consistently the same results. (You have tested this for example on Figures 8 and 9.) This suggests that for everyday Earth-bound observations there is nothing to choose between the two alternative models. Is there any observation at all that would indicate any preference for one of the two?

Well, there is just one. You may remember that in Section 3 a reference was made to the fact that if the position of either Mars or Jupiter (or any other planet for that matter) is plotted night by night with respect to a chosen constellation or to a fixed reference star, this change of position is not uniformly in one direction. Occasionally it would appear as if the planet changed its mind and started going back for a while, but soon returned to its initial forward path again (Figure 5). This behaviour would be very odd indeed, if we were to believe that the Earth is stationary and the Sun as well as all the planets travel around it. There is no obvious reason why Mars or Jupiter should have such complicated orbits, there is no other large body anywhere near them that could perhaps temporarily deflect them from their more orderly paths.

Could this odd behaviour be understood or explained in a simple way if one were to assume that the Sun is stationary and the Earth is orbiting around it, together with all the other planets? (Incidentally, this model is known as a *heliocentric model*, because the Sun (*helios* in Greek) is located in the centre of a planetary system which includes the Earth. Sometimes it is also referred to as the *Copernican model*, after the Polish astronomer Copernicus (1473–1543), who worked out in detail the motions of all the planets around the Sun.)

heliocentric

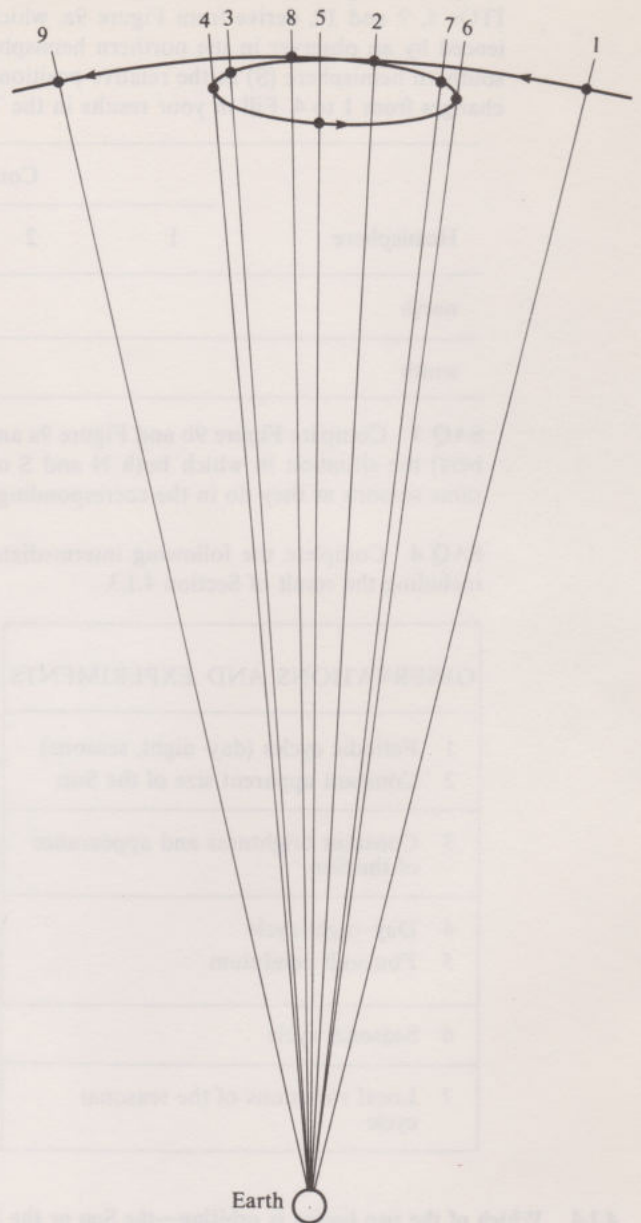
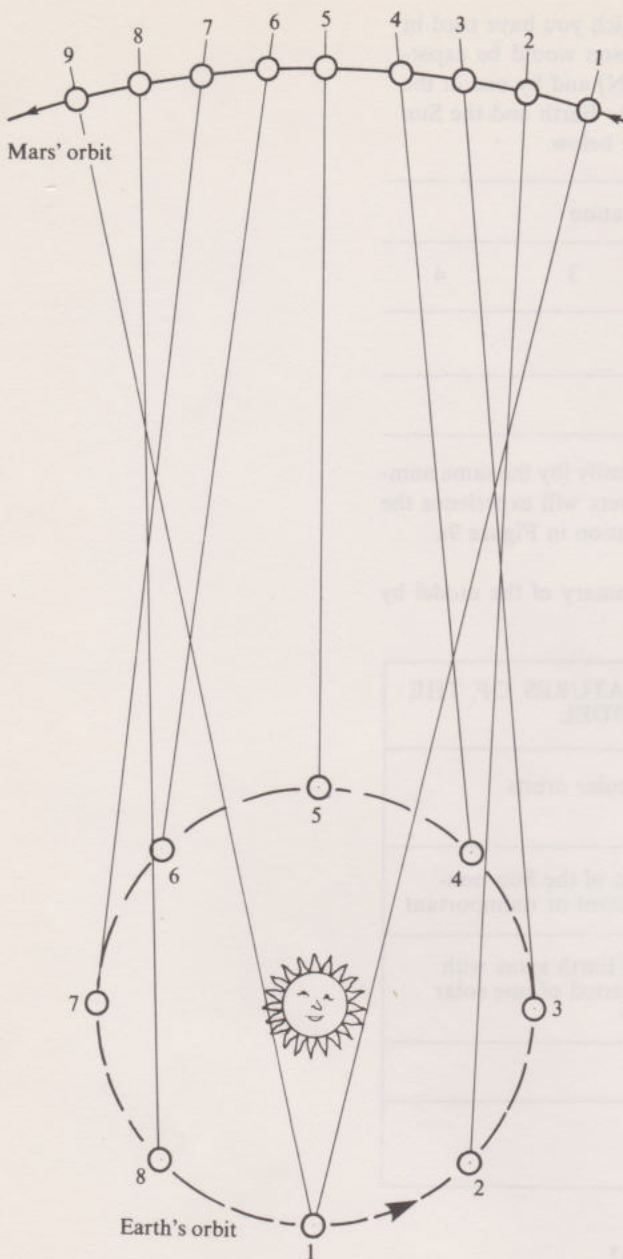


FIGURE 10 The orbit of the planet Mars. Left: A God's eye view of the two planets with respect to the Sun.

Right: The path of Mars as seen from the Earth.

Directions numbered 1-9 are transferred from the left diagram to the right, and brought to one point. An Earth-bound observer believes that he is stationary.

The heliocentric system does offer a very simple explanation for the retrograde motion of the planets. This explanation is based on the fact that different planets move along different sized orbits, and the larger their orbits, the longer their orbital periods. Thus, for example, Mars takes about twice as long as the Earth to complete one orbital turn. The apparent retrograde loop of Mars results from the combination of orbital motions of the two planets at the moment when the Earth overtakes Mars with respect to the Sun (position 5 in Figure 10). Notice that in order to save space the motion of Mars in Figure 10 is 'slowed down', in reality Mars would cover about half of a circle between 1 and 9. But this does not change the principle. Numbers 1 to 9 indicate simultaneous positions of the two planets. An Earth-bound observer is not aware of his own motion with the Earth. He regards himself as *stationary*, but the direction in which he sees Mars keeps changing (compare lines connecting simultaneous positions 1-1, 2-2, etc.).

To make it clearer, the directions from the left part of the picture are all brought together to one point in the right-hand side of Figure 10. If you inspect the sequence of directions, starting from 1, it goes initially from right to left, but it reverses temporarily (left to right) before resuming the initial tendency again.

Incidentally, the width of the backward loop in Figure 10 is exaggerated for the sake of clarity. In practice, the loops are very narrow, since their width is

determined by the relative inclination between the two planes of planetary orbits (those of the Earth and the other planet). For most planets this inclination is only 1° – 3° , the two exceptions being Mercury (7°) and Pluto (17°).

Thus, in concluding Section 4.1, we have found a good reason to prefer the heliocentric model to the geocentric one: the motion of the planets is very much simpler if the Sun, rather than the Earth, is taken to be the centre of the whole planetary system.

4.2 The Moon and its relationship to the Earth and the Sun

The most striking observation about the Moon is the periodic cycle of phases as described in Section 3.3. The continuously changing shape and size of the bright part rules out any possibility that the light from the Moon *originates* in the Moon itself. It is very difficult to imagine any physical process, taking place on the surface of the Moon, that could switch different parts on and off with such unflinching regularity and with such a sharp boundary between dark and light.

On the other hand, the low overall brightness, the lack of heat and the shape of the bright crescents can be readily understood by assuming that the Moon is a *spherical body, illuminated by the Sun and reflecting some of its light*.

But how is the Moon placed with respect to the Sun and the Earth and how does it move? What features should a three-sphere model have in order to account for all the observations?

Well, you already know that the Earth moves in a circular orbit around the Sun, completing one circle in one year. As it goes around the Sun it also spins about an axis (tilted with respect to the plane of the orbit), completing one turn in one solar day. You also know that the apparent size of the Moon does not change. Even if you see only a narrow bright crescent, if you were to complete the circle that corresponds to the crescent, the size of the circle would be the same as that of the full Moon.

Thus the *distance* between the Earth and the Moon must be *constant*. And there are only two ways in which this could be true. Either the Moon moves *alongside the Earth* in a single circle around the Sun, or else it *orbits around the Earth* in a circle as it follows the Earth around the Sun.

The first possibility is easily discounted. Can you see why? Look at Figure 11. In this configuration there would be no lunar phases. The Moon would look the same at all times to an observer at any one place on the Earth, although it would look different to observers at different places. You may amuse yourself for a while by trying to imagine how you would see the Moon if you were sitting somewhere in the northern hemisphere of the Earth and if the Moon were moving alongside the Earth. Consider six different possibilities: inside or outside the Earth's own orbit, ahead, behind or exactly on the Sun–Earth line (Figure 11).

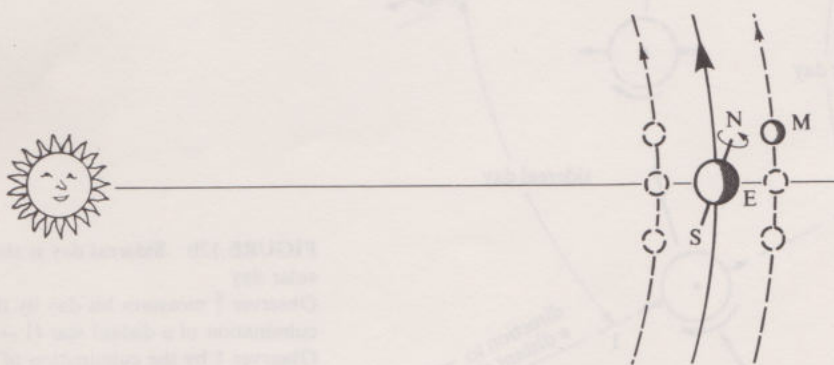


FIGURE 11 Can the Moon travel alongside the Earth?

So, in order to account for the phases (Figure 4), the Moon must be moving *around* the Earth. And since the whole cycle of the phases has a period of about 28 solar days, this is likely to be the time it takes the Moon to complete one circle around the Earth.

An aside: solar time and sidereal time

It sounds simple enough to say ‘the Moon completes one circle around the Earth’. But there are two equally good and yet different meanings that this statement can have. Follow the progress of both the Earth and the Moon in Figure 12a, starting from position 1. It is perfectly reasonable to say that the Moon has completed a circle when both bodies are in position 2, because the Earth–Moon direction *in space* (with respect to distant stars) is the same as it was in 1. But it is equally reasonable to argue that, *with respect to the Sun*, the Moon has not completed its full circle in 2. Both the Earth and the Moon have to move a little bit more, to position 3, before the Moon is in the same relative configuration with the Earth and the Sun as it was in position 1.

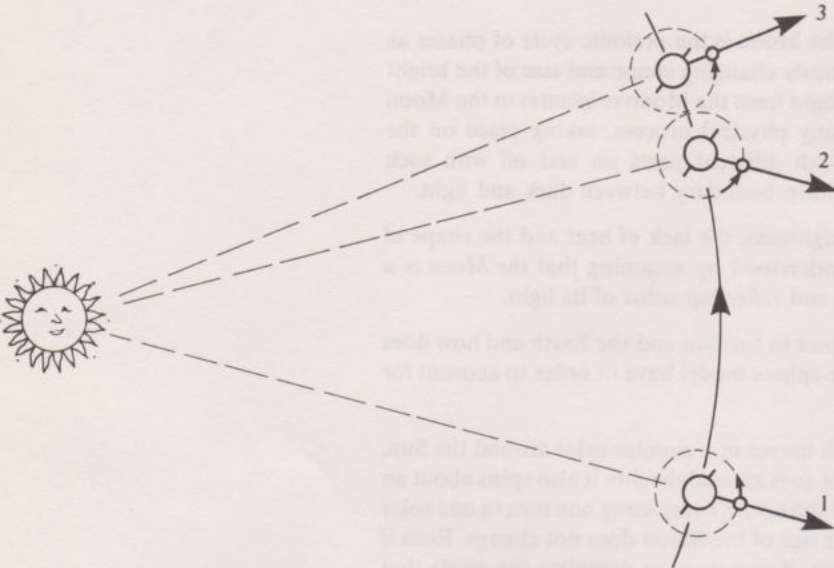


FIGURE 12a Solar time and sidereal time

Thus it is useful to distinguish between solar time and sidereal time. An Earth-bound observer can choose as his unit of time either two consecutive culminations of the Sun (solar day) or two consecutive culminations of a distant bright star (sidereal day). As Figure 12b shows, sidereal day is shorter (by about 3 minutes 56 seconds) than solar day. Solar time provides the basis for the standard calendar time; sidereal time is used by astronomers (it is both more regular and more relevant to all events and observations outside the Sun–Earth system).

sidereal day

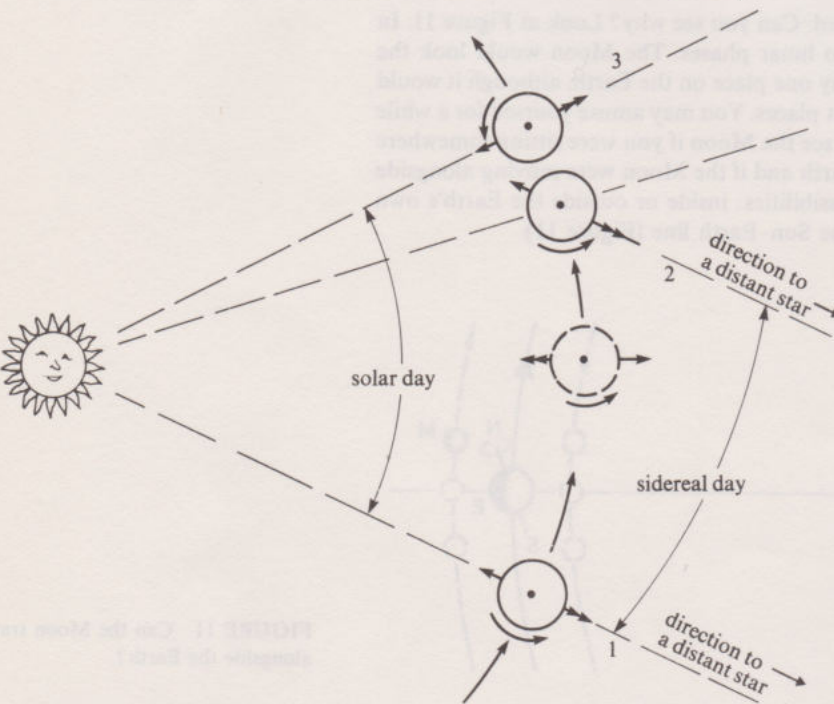


FIGURE 12b Sidereal day is shorter than solar day
Observer $\hat{\uparrow}$ measures his day by the culmination of a distant star (1 $\rightarrow$ 2).
Observer $\uparrow$ by the culmination of the Sun (1 $\rightarrow$ 3).

To return to our main argument, having established that the Moon cannot simply travel parallel to the Earth but must orbit around it in a circle, you should ask yourself the question: How is the lunar orbit related to the main orbit of the Earth? This is not a trivial question, as you will realize by looking at Figure 13. There can be an infinitely large number of different circular orbits of the same

diameter, all within one spherical surface. Since you cannot easily tell which is the most likely one, you may as well start by looking at two particularly distinct options and comparing how they would fare in confrontation with real observations.

Let us first assume that the plane of the lunar orbit is *identical* with the plane of the Earth's orbit. Imagine yourself to be somewhere in the northern hemisphere of the Earth in Figure 14 and consider how and when you would see the Moon as it travels around. (Remember, both the Earth's orbit and the lunar orbit lie in the plane of the paper.)

In trying to imagine how you would see the Moon during each day (one spin of the Earth) it might be helpful to note that the orbit of the Moon in Figure 14 (as well as in the later Figures 15, 16, 17 and 18) is *not drawn to scale*. The distance of the Moon from the Earth is about 30 times larger than the size of the Earth and to draw this relationship to scale would be wasteful of paper! But because of this large distance, the *appearance* of the Moon will not change between, say, the evening and the morning, although the observer's position has changed as the Earth spins. If you are having difficulties in visualizing the likely appearance of the Moon, you will get considerable help from the TV programme associated with this Unit (TV 01).

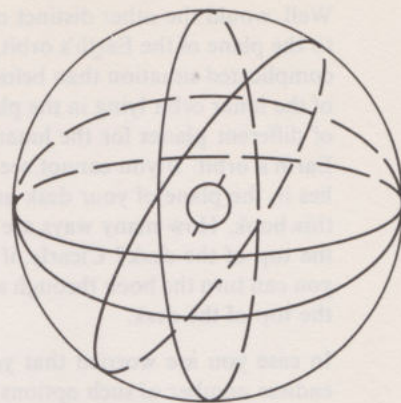
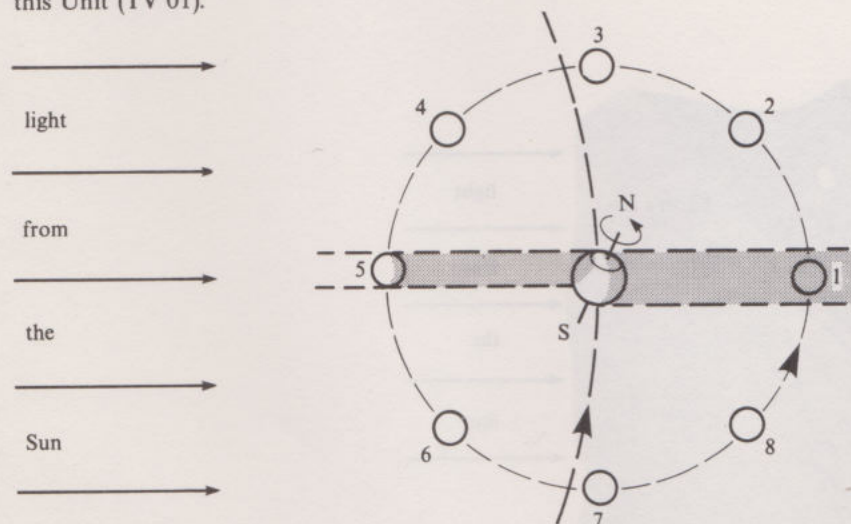


FIGURE 13 All possible circular orbits with a common centre and equal radius define a sphere.



FIGURE 14 Showing the orbit of the Moon lying in the same plane as the Earth's orbit.

ITQ 11 Insert the appropriate numbers from Figure 14 in the brackets to identify the situations in which the statements listed below are true. Refer to Figure 4 (repeated here for convenience) to remind yourself of the names for different phases and of the times when the Moon is above the horizon.

- A The Moon is in the waxing crescent phase ()
- B The Moon is eclipsed by the Earth ()
- C The Moon is in the last quarter ()
- D The Moon is in the waning gibbous phase ()

ITQ 12 Describe the phases observed in the other positions, not included in ITQ 11.

ITQ 13 Identify by numbers from Figure 14 the situations in which the Moon is above the horizon at the following times:

- A Afternoon and first half of the night ()
- B Most of the night and early morning ()
- C All day ()
- D Evening and most of the night ()

Check that your answers to ITQ 13 agree with ITQs 11, 12 and with the observations summarized in Figure 4.

Thus it is very encouraging to see that this choice of the lunar orbit (in the same plane as the orbit of the Earth) seems to reproduce the cycle of phases quite well. The only problem is that, from Figure 14, you could expect a full eclipse of the Moon *every month* (position 1). And similarly you would predict regular monthly eclipses of the Sun, when it is covered by the disc of the Moon (position 5). In practice, however, eclipses are much less frequent. So the choice could not have been quite right after all.

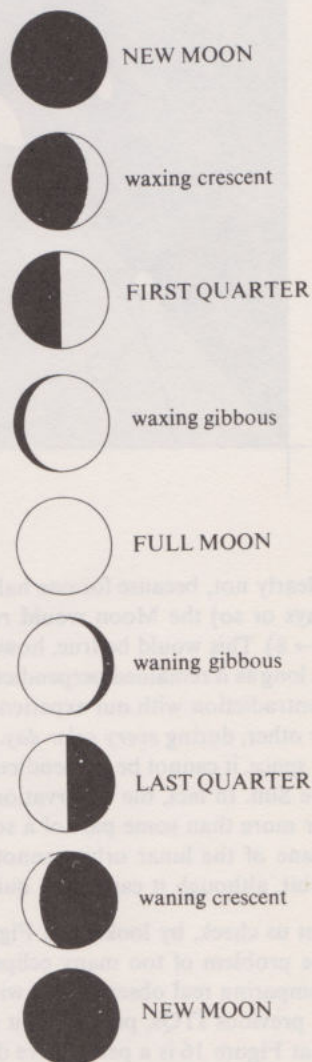


FIGURE 4 Phases of the Moon.

Well, would the other distinct option, namely that of a lunar orbit *perpendicular* to the plane of the Earth's orbit, do any better? At first sight this is a much more complicated situation than before. Can you see why? There is *only one* possibility of the lunar orbit lying in the plane of the Earth's orbit. But there are *any number* of different planes for the lunar orbit that are perpendicular to the plane of the Earth's orbit. If you cannot see this immediately, imagine that the Earth's orbit lies in the plane of your desk and the lunar orbit in the plane of the title page of this book. How many ways are there for you to make the book perpendicular to the top of the desk? Clearly, if you start from one such perpendicular position, you can turn the book through a full circle and it will still remain perpendicular to the top of the desk.

In case you are worried that you are now going to be asked to go through an endless number of such options until the cows come home, do not despair! They can all be eliminated at a single stroke.

Look at Figure 15, which shows in a perspective drawing just one, arbitrarily chosen, perpendicular lunar orbit. If you were an observer in the northern hemisphere, would you see the Moon, if only for a short while, during *each* spin of the Earth (each solar day)?

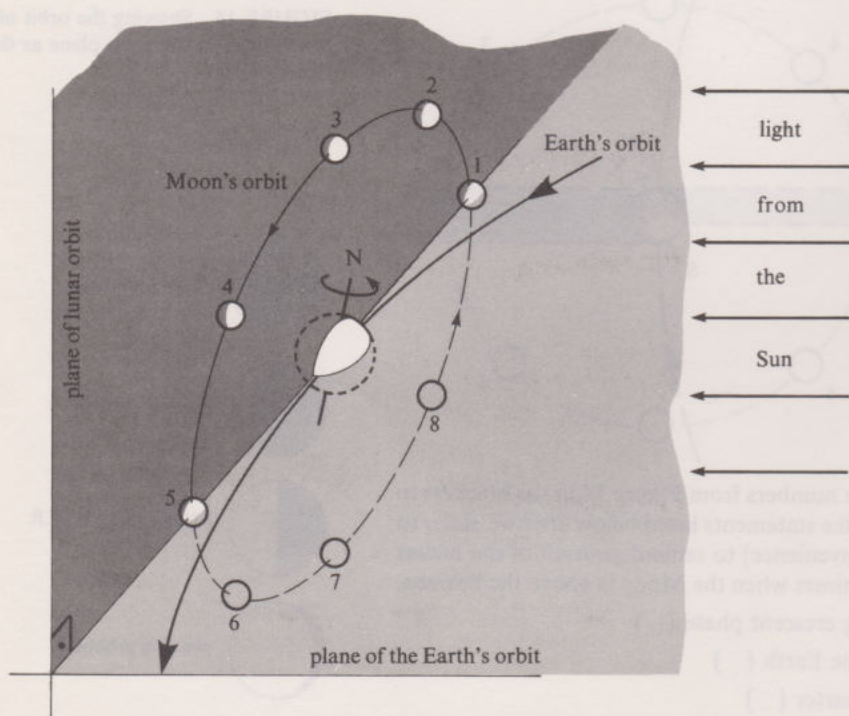


FIGURE 15 The plane of the lunar orbit perpendicular to the plane of the Earth's orbit.

Clearly not, because for one half of its way around the Earth (that is for some 14 days or so) the Moon would remain below the level of your horizon (between 5 → 8). This would be true, however you have turned the plane of the lunar orbit, as long as it remained perpendicular to the plane of the Earth's orbit. And this is in contradiction with our experience. The Moon *is* above the horizon, at some time or other, during *every* solar day. Thus, whatever the orientation of the lunar orbit in space, it cannot be perpendicular to the plane in which the Earth travels around the Sun. In fact, the observation that the Moon is never quite below the horizon for more than some part of a solar day, clearly supports the conclusion that the plane of the lunar orbit cannot be *very* different from the plane of the Earth's orbit, although it cannot be quite identical with it, as you saw before.

Let us check, by looking at Figure 16, if a *slightly inclined* lunar orbit can cure the problem of too many eclipses. Since you have already practised the skill of comparing real observations with predictions from model drawings in a number of previous ITQs, perhaps you can try to answer the following SAQs now. Note that Figure 16 is a perspective drawing, in which circular orbits appear elliptical. This is necessary to convey the impression of their relative inclination. Note also that although one half of the lunar orbit is now below the plane of the Earth's

orbit, the inclination is sufficiently small for the Moon to remain visible from the northern hemisphere even at the lowest point of its orbit. This is helped by the fact that the Earth's axis of spin is also inclined with respect to the plane of the Earth's orbit (remember Section 4.1.2; more about this point will follow in the next Section 4.3).

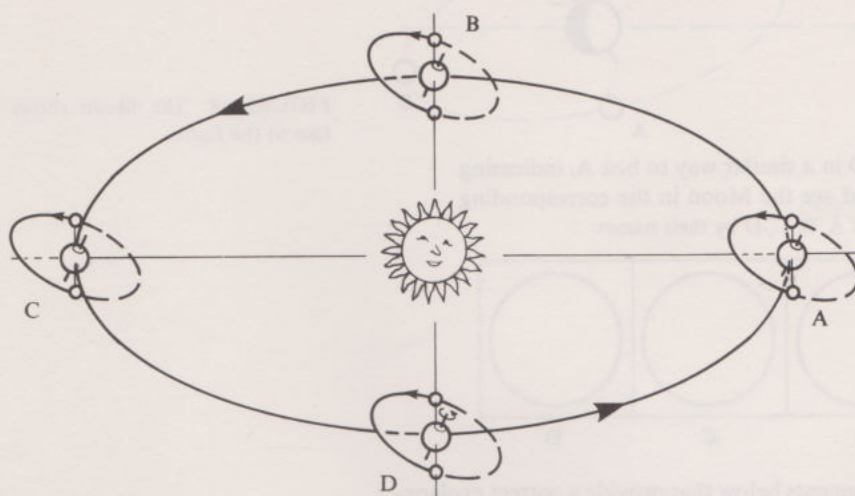


FIGURE 16 The lunar orbit is slightly inclined to the plane of the Earth's orbit.

SAQ 5 Can there be any eclipses of the Sun or the Moon when the Earth is in position A?

SAQ 6 Analyse situations B, C and D in a similar way and identify when eclipses can occur.

So the very slight inclination of the lunar orbit, just sufficient to bring the Moon above or below the Sun–Earth line in and around positions A and C, brings our model in full agreement with observations. According to our modified model, eclipses cannot happen every month, but they can, indeed they must, happen at approximately half-yearly intervals, when the three bodies are in configurations B or D.

Eclipses hold some considerable emotional attraction for the general public and scientists alike, but there is not space in this Unit to go into any details. For the purposes of this Course, you only need to understand why and approximately how often eclipses can happen. In addition, Figure 17 should help you to realize why a total eclipse of the Sun is visible only for a short while and from a limited area of the Earth's surface, whereas a total eclipse of the Moon can be seen from anywhere on the Earth. (The distances are grossly reduced and the angles of shadows consequently exaggerated.)

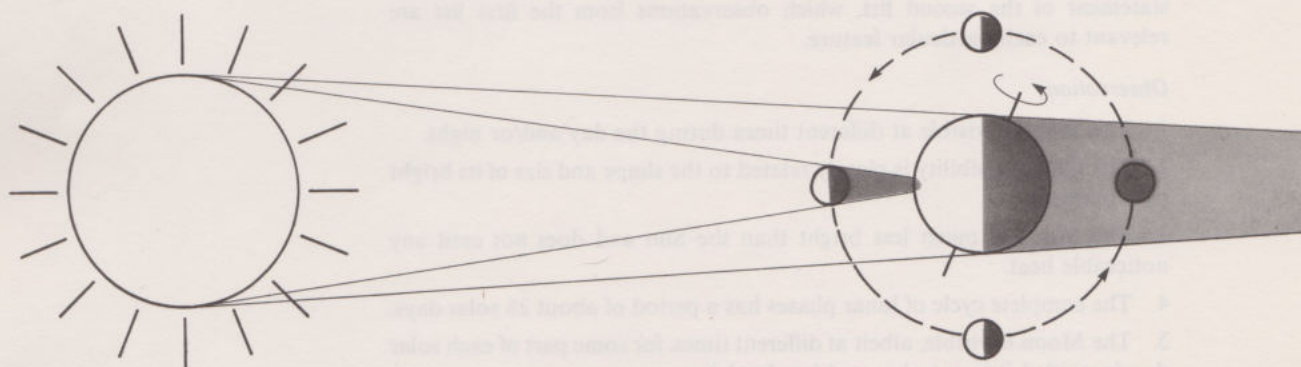


FIGURE 17 Eclipses.

There is just one more important observation about the Moon that has not been built into our model so far. How is it that from the Earth one can always see only one and the same side of the Moon? How can this observation be related to the orbital motion of the Moon that had to be introduced into the model in order to account for the cycle of phases?

Figure 18 shows the orientation of one selected surface feature (indicated by a short line) with respect to the Earth during one orbital turn of the Moon. The same feature is marked by a dot in box A within the next SAQ.

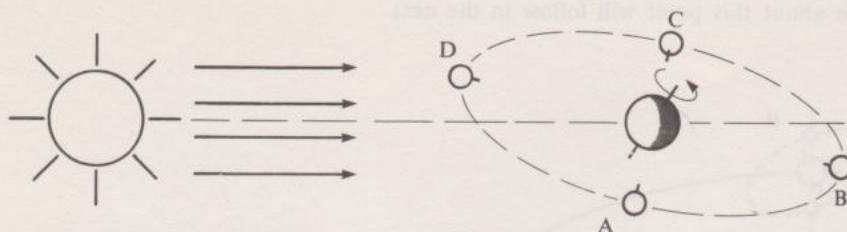
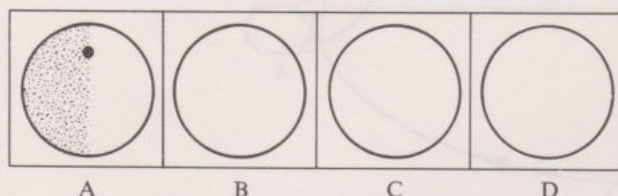


FIGURE 18 The Moon shows the same face to the Earth.

SAQ 7 Complete boxes B, C and D in a similar way to box A, indicating how an Earth-bound observer would see the Moon in the corresponding positions in Figure 18. Identify phases A, B, C, D by their names.



SAQ 8 Select *three* of the statements below that provide a correct explanation for seeing the same face of the Moon.

- The Moon has no spin.
- The Moon spins.
- The axis of spin lies in the plane of the orbit of the Moon, and points towards the Earth.
- The axis of spin is perpendicular to the plane of lunar orbit.
- The period of spin is exactly equal to the orbital period of the Moon.
- The period of spin of the Moon is the same as the period of spin of the Earth.
- The period of spin is the same as the Earth's orbital period.

We are now in a position to formulate a summary of the important features of the Moon's relationship to the Earth and the Sun. Since one of the important Objectives of the last few Sections has been to develop your appreciation of, and your skills in, relating observations to the features of a model, it is proper for *you* to draw up the concluding summary of Section 4.2. You can do so in your own words if you wish. Alternatively you can do it by completing SAQ 9.

SAQ 9 There follow two lists of statements. One list contains observations relating to the Moon as seen from the northern hemisphere of the Earth. The other list contains features of a three-body system representing the Sun, the Earth and the Moon. Indicate, in the brackets after each statement of the second list, which observations from the first list are relevant to each particular feature.

Observations

- The Moon is visible at different times during the day and/or night.
- The time of visibility is closely related to the shape and size of its bright part (phases).
- The Moon is much less bright than the Sun and does not emit any noticeable heat.
- The complete cycle of lunar phases has a period of about 28 solar days.
- The Moon is visible, albeit at different times, for some part of each solar day (provided it is not obscured by clouds).
- The Moon shows the Earth the same face at all times.
- The apparent size of the Moon remains unchanged.
- The apparent size of the Moon is about the same as that of the Sun.
- Total eclipses of the Moon occur at the full moon phase, approximately twice a year.

Features

- A The Moon is a spherical body reflecting the light from the Sun ()
- B The Moon orbits around the Earth in a circle ()
- C The orbital period of the Moon is about 28 solar days ()
- D The plane of the lunar orbit is slightly inclined with respect to the plane of the Earth's orbit ()
- E The Moon spins with a period equal to the period of its orbital motion, the axis of spin being perpendicular to the plane of the orbit ()

4.3 The Earth and the stars

During each night all the stars appear to be moving in circles, all in the same direction and always keeping constant relative distances from each other (the shapes of constellations never change). In the northern hemisphere this rotation has as its *fixed centre* a star known as the Pole Star, the Northern Star or Polaris.

Since you already know that the Earth spins about an axis whose direction is fixed in space (Sections 4.1.2 and 4.1.3) and that this spin explains the apparent circular path of the Sun, it is only natural to assume that the apparent rotation of the stars is also explained by the spin of the Earth.

Can you think of a simple experiment by which this assumption can be tested? You could, for example, set a photographic camera on a firm support and aim it so that the Pole Star was at the centre of the field. Then if you were to leave the shutter open sufficiently long, say for at least four hours, you would get a photograph looking something like Figure 19, where the length of the individual arcs would depend on the length of exposure.

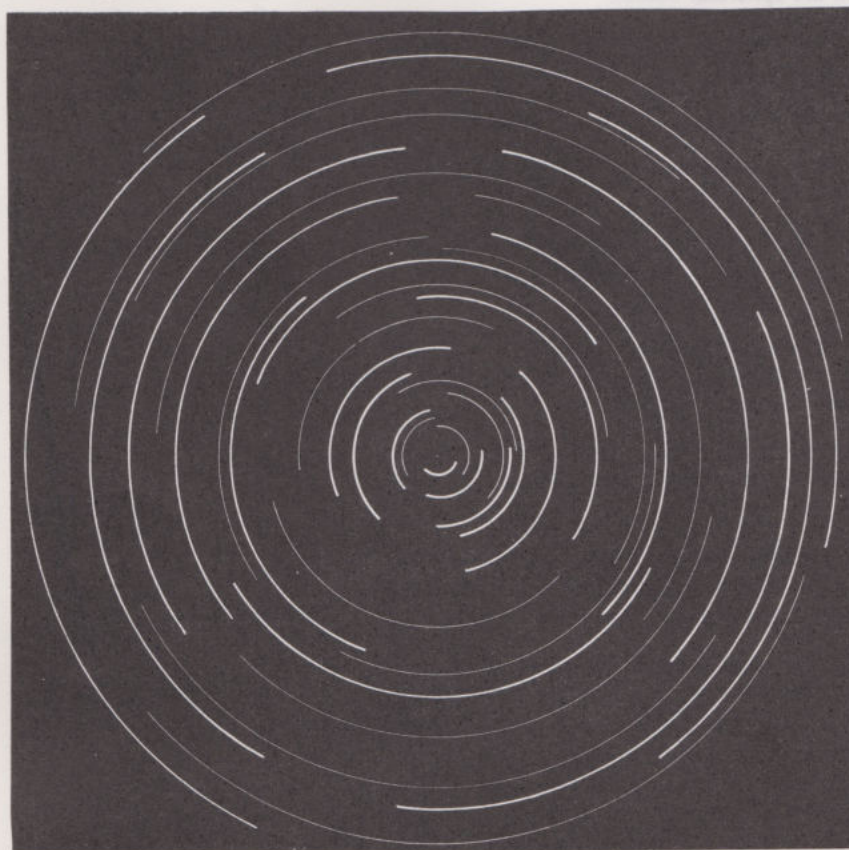


FIGURE 19 A long-time exposure photograph of the night sky (the Pole Star at centre), showing the motion of the stars.

(Note that in order to increase the clarity of this copy, some bright tracks were emphasized and many weaker tracks suppressed.)

ITQ 14 Select one of the more distinct tracks in Figure 19 and estimate approximately what fraction of a full circle it represents. Then select one of the following exposures that would, in your view, produce such a picture. 2 hours, 4 hours, 8 hours, 12 hours, 24 hours.

The length of the star tracks from such photographs supports the assumption that the apparent motion of stars is due to the spinning of the Earth. If that is so, then the only possible explanation for the fact that the *Pole Star* never moves is that it lies exactly in the direction of the Earth's axis of spin.

Thus we can now combine this conclusion with the previous result derived in Section 4.1.3. In order to explain the seasonal cycle within one year and its local variations at different parts of the Earth's surface, it was necessary to accept that the axis of spin is *tilted* with respect to the plane of orbit. In fact, for the best agreement with all observations the axis must be at an angle of about 67° to the plane of the orbit (Figure 20). Now we know that this direction is also the direction to the Pole Star.

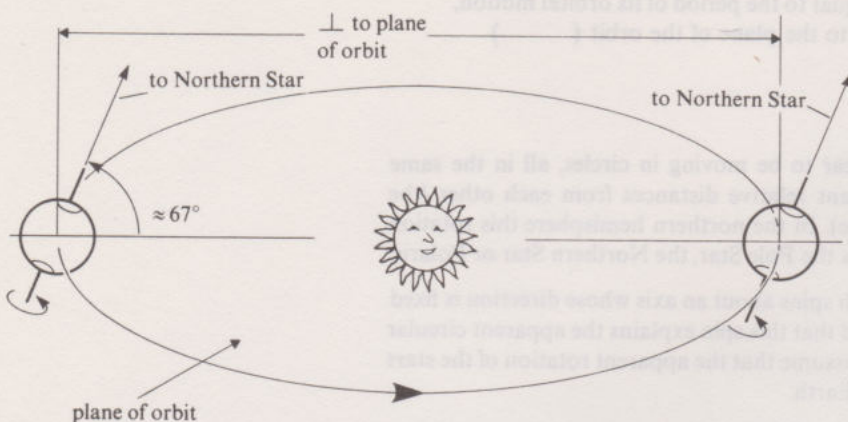


FIGURE 20 The axis of spin of the Earth points permanently to the Pole Star ($\perp$ means perpendicular)

4.4 A summary of the model

- 1 The Sun, the Earth and the Moon are spherical bodies.
- 2 The Sun radiates light and heat evenly from every part of its surface (hence spin would not be noticeable, even if it existed).
- 3 The Earth spins about its axis and the spin accounts for the day–night cycle.
- 4 The Earth orbits around the Sun in a circle and one complete circle corresponds to one complete seasonal cycle (one year).
- 5 The axis of the Earth's spin is inclined at about 67° to the plane of its orbit, remains fixed in space and points towards Polaris. The tilt of the axis of spin accounts for seasonal variations.
- 6 The Moon reflects sunshine and orbits around the Earth in circles. During one orbital period (one month) the Moon goes through a cycle of phases, explained by its relative positions with respect to the Sun and the Earth.
- 7 The plane of the lunar orbit is slightly inclined with respect to the plane of the Earth's orbit. This explains the observed visibility of the Moon above the horizon as well as the frequency of eclipses.
- 8 The Moon spins about an axis perpendicular to the plane of its orbit and the period of its spin is exactly equal to the period of its orbital motion around the Earth. This explains why the same face of the Moon is seen at all times.

Now, it is important to emphasize once again that statements 1 to 8 are features of the *simplest possible model* of the three bodies – the Sun, the Earth and the Moon – that are in reasonable agreement with *everyday observations*. As soon as one takes a more careful look, using accurate instruments for measuring time differences, angular sizes and positions of celestial bodies, the model has to be refined. Thus it will be found that the Earth is not *perfectly* spherical, although by eye you could not tell the difference when looking at the photograph at the beginning of the Unit. Similarly, the Earth's orbit is not *exactly* circular, although the difference from the circle would not be noticed if the orbit were reduced to the size of this page. Because of this slight deviation, the solar day is not exactly identical throughout the year and so on.

But this does not mean that our simple model is wrong. Science is a continuous process in which more accurate models and explanations are developed from simpler ones. The question of accuracy is a relative one. One and the same model, assumption or theory can be perfectly adequate for one purpose and not sufficient for another.

5 A short concluding discussion

With this Unit you are only beginning your acquaintance with science. So, if you were to ask yourself what you have *learnt* so far, the answer would depend far more on your previous knowledge than on the content of these pages. Perhaps you found no new facts, no new piece of information at all.

But then this was not the purpose of the Unit. Science is not about reading what other people know or have done. First and foremost, in this Unit the Course Team wanted to convey to you that science is about an *attitude of mind*. This is the meaning of the motto at the start of this Unit and indeed of the whole Course. Einstein, whose words we quoted, is generally regarded as one of the greatest scientists that ever lived. Yet all his scientific achievements were firmly based on deep critical analysis of facts already known, whether from everyday experience or from more accurate, quantitative observations and experiments. They were not inventions independent of everyday reality.

In a similar way, you have been following and taking an active part in the process of constructing a simple scientific model from an analysis of everyday observations. Now step back and have a critical look at some aspects of this process.

5.1 Assumptions of the model

Before one can say anything about the quality or usefulness of any particular model, it is necessary to be aware of the whole process by which it was built up. In that process there might have been some steps that looked perfectly obvious and yet may have contained hidden *assumptions* whose validity or falsity was neither questioned nor tested. There are at least two such assumptions involved in the way we have arrived at some conclusions about the shape of the Earth and about the configurations and motions of celestial bodies. Both of these assumptions concern the *properties of light*, and they can be important, since all evidence and information we have used was based on visual observations. Can you think what these assumptions were?

1 In thinking about the shape of the Earth (Figures 1 and 2) we have assumed, without saying so, that *light always travels in a straight line*. But does it?

2 In considering the relative motions of distant planets and stars we have assumed that *light travels infinitely fast*, that at the moment when the light reaches the eye the object where it comes from is exactly where we *see* it. But is this true?

Well, both of these assumptions are wrong. You will find out later (unless you already know) that a beam of light changes direction when it travels from one transparent medium into another (air to water, air to glass, air of low pressure to air of high pressure). Similarly the speed of light is finite and although it is very large (about a thousand million kilometres per hour), by comparison with normal travel speeds it still takes about eight minutes for the light from the Sun to reach the Earth. The light from some of the most distant galaxies that is reaching the Earth now has been on its way for thousands of millions of years.

Is our model of the solar system completely useless because both of these assumptions are incorrect?

Certainly not. What this example illustrates is one of the most important lessons of science. There are no such things as *absolute truth*, *absolute accuracy*, *perfect models*, *complete knowledge*. One and the same piece of knowledge can be more that sufficient in one situation, just about adequate in another, and quite useless in the third. Everything has to be *judged in its context*; judged by the purpose for which it is used.

In our case, all we have done so far has been to derive from experience a very primitive, qualitative model. It tells us only what *kind* of relative motions the bodies must have, but it does not give us any *details* about their true sizes, their true distances and the small deviations and variations in their basic motions. Within this general, qualitative aim, both assumptions about the propagation of light are sufficiently accurate. But when it comes to constructing a *more exact quantitative model*—one that correctly represents distances, sizes and directions—both of these assumptions could lead to wrong conclusions. The real properties of light would have to be taken into account.

5.2 What makes a good model?

There are several different aspects to the question, what makes one particular model a good one.

First of all, any model worth considering *must adequately explain all experience available at the time*. But it is often possible that the same set of observations can be explained by more than one model. In our case, all such observations as the day–night cycle, the seasonal cycle, the lunar phases, the lunar and solar eclipses and the motions of stars could be equally well explained by either a geocentric or a heliocentric model. Any preference for one model must take into account aspects other than just good agreement with present experience.

One additional guide for choosing between alternative models is the way in which they can cope with *new observations*. It is an important indication of the quality and suitability of a model if new observations, not available at the time when the model was formulated, can be accommodated by it without requiring any major revision of either its assumptions or its features.

All other things being equal, a clear preference should also be given to a model that leads to the *prediction of new effects*, verifiable by observations or experiments. In a sense, it is true to say that a good model should live dangerously, that it should expose itself to many tests. If a model predicts an effect and the effect does not happen, the model has to be either rejected or substantially modified. On the other hand, if a predicted effect is confirmed, it does not mean that the model is *proven*. It only means that it is a good model *so far*, that it has withstood one more test. But there may come a time when it will fail one of the future tests.

It is an important aspect of scientific thinking that you *do not look for a complicated explanation where a simpler one will do just as well or even better*. For example, when Pythagoras first suggested that the Earth is of spherical shape (just like the Sun and the Moon), many puzzling questions (such as whether the Sun at sunrise is the same body as the one that set on the previous night) were immediately solved or at least simplified. Similarly, when it comes to understanding the motion of the planet Mars in the skies, the heliocentric model offers a simple explanation, whereas a geocentric model has to invent additional features to describe this seemingly tortuous passage. Thus, if more than one model seems to fit a given set of data, the one to go for (the good one) is chosen on one or all of the following criteria:

- it has the smallest number of assumptions or features;
- it offers the simplest explanation of complex observations;
- it offers the widest range of predicted new observations.

In order to solve a particular scientific problem, it is often necessary to limit its scope and size, to leave some of its aspects out of consideration. Without this concentration on individual, limited and isolated problems nothing would ever be solved. But there are dangers. It may well happen that a set of experiments and observations relating to one particular problem could be suited by a model that satisfies the criteria listed above. And yet the model could contain a fatal flaw. No doubt this would eventually reveal itself, since no model that is based on a completely wrong assumption or has a built-in feature that contradicts the laws of nature can survive for ever. But it could take a long time if those who proposed the model had blinkers and did not look beyond their own laboratory (or armchair).

All assumptions and all features of any new model have to be set against the bulk of *knowledge already existing outside the model itself*. In this way, one can often see quickly and early why a particular new model simply cannot be true because it contradicts some well-known general laws of nature.

5.3 What next?

The model of the Sun–Earth–Moon relationship, summarized in Section 4.4, is a qualitative one. Throughout its derivation in this book you did not have to use a single formula or equation. And yet in a very broad sense this derivation has been mathematical, in that you were making choices between different possibilities and options, eliminating the wrong ones on the basis of combining observed facts with logical, scientific reasoning.

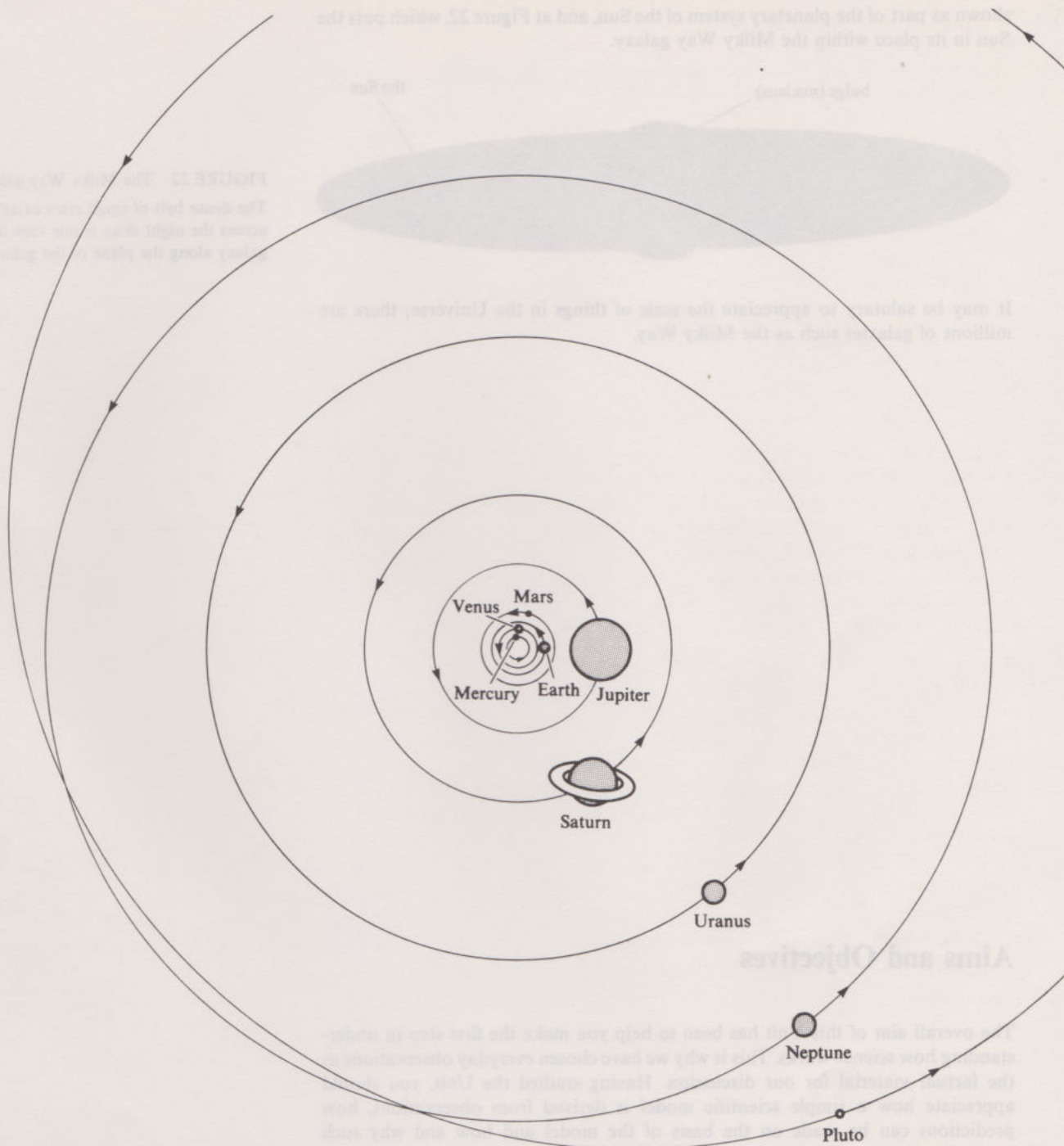


FIGURE 21 Planetary system of the Sun. The sizes of the planets are shown in correct proportion to each other. The *orbits* are also shown in approximately correct proportion to each other. But the dimensions of the orbits are *not* in correct proportion to the sizes of the planets. If the orbits were to be drawn on the same scale as the sizes of the planets, this page would have to be at least one kilometre wide! The Sun is about ten times larger than Jupiter and so it cannot be shown at the centre of this drawing.

This approach is fine as far as it goes, but it does not go far enough. Our curiosity is not satisfied by having established that the Earth moves around the Sun and that the Moon orbits around the Earth. What about their sizes, their distances, their composition, their relationship to other bodies? It is all very well knowing how the three bodies move with respect to each other, but what about the actual speeds with which they move? And *why* is it that they move the way they do? Is there any underlying mechanism or principle that could explain the motion of all celestial bodies?

In order to seek answers to these questions, you will have to make a step forward, a step from qualitative observations to *measurements*. And you will be making that step in Unit 2. In the meantime have a look at Figure 21, where the Earth is

shown as part of the planetary system of the Sun, and at Figure 22, which puts the Sun in its place within the Milky Way galaxy.

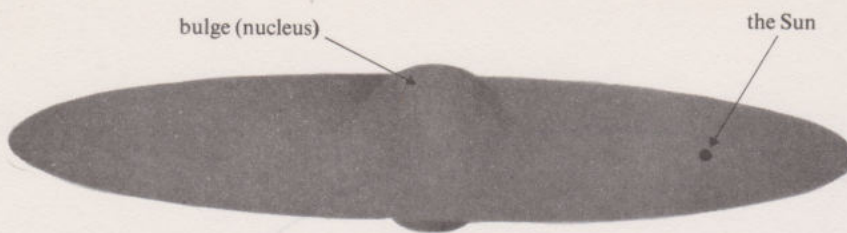


FIGURE 22 The Milky Way galaxy. The dense belt of small stars extending across the night skies is our view across the galaxy along the plane of the galactic disc.

It may be salutary to appreciate the scale of things in the Universe; there are millions of galaxies such as the Milky Way.

Aims and Objectives

The overall aim of this Unit has been to help you make the first step in understanding how science works. This is why we have chosen everyday observations as the factual material for our discussion. Having studied the Unit, you should appreciate how a simple scientific model is derived from observations, how predictions can be made on the basis of the model and how and why such predictions are tested by new observations and experiments.

Some more specific aspects of this overall aim are listed below as more detailed Objectives and related to in-text questions (ITQs) and self-assessment questions (SAQs). In particular you should now be able to:

- 1 Describe the motion of the Earth around the Sun. (ITQs 8, 9, 10, SAQs 2, 3, 9)
- 2 Describe the motion of the Moon with respect to the Earth and the Sun. (ITQs 11, 12, 13, SAQs 5, 6, 7, 8)
- 3 Explain local variations of the seasonal cycle. (ITQs 8, 9, 10, SAQ 2)
- 4 Explain the phases of the Moon. (ITQs 11, 12, 13)
- 5 Distinguish between orbital motion and spin (Section 4.1.1)
- 6 Describe what is meant by a periodic process and what is the period. (Section 3.5, ITQs 3–6)
- 7 Explain apparent motion of the stars. (ITQ 14)
- 8 Distinguish between observations, assumptions and features of a model. (SAQ 1)
- 9 Correlate systematic observations (such as the sequence of seasons, lunar phases, etc) with the features of a model. (ITQs 1, 7–14, SAQs 2–9)

ITQ answers and comments

ITQ 1 One observation cannot distinguish between various possible shapes of a curved surface. For most surfaces shown in Figure 3 the rate of curvature would be different at different points of observation and in different directions. On the surface of a cylinder there is even one direction along which there is no curvature at all and many directions of no curvature can be found on a cone (looking from the tip). A sphere on the other hand can be described as having *the same curvature* in all directions at any point on its surface. Thus to show that the surface of the ocean is spherical, one would have to show that a ship departing from one point in different directions *always disappears at the same distance*. Moreover, this distance of disappearance would have to be the same in all directions *from all points of departure*.

ITQ 2 If your turntable is any good and if your measurement was not way out (for example, because of miscounting the turns), then the time you measured for 10 and 20 turns should have been 18 seconds and 36 seconds respectively. Thus the period, which is the time taken to complete one turn, is 1.8 seconds. It is obviously better to measure the time over more turns. The most likely errors are involved in starting and stopping the time count *exactly* when the first turn begins and when the last turn ends. These two errors are likely to be the same, whether there are 8 or 98 turns between them. For example, if you start your stop-watch one second before the turntable begins to turn then this error will add 0.1 seconds to the true value of the period, when measured over 10 turns. But the same error will only add 0.01 seconds to the value of the period when 100 turns are measured. You will learn more about experimental errors in Units 2 and 3.

ITQ 3 No, it does not matter at which point you start the counting, provided you always count complete swings through both extremes and back to the same point again. It is a matter of *convenience* to regard one of the extreme positions, or the central (vertical) position, as the beginning of the swing because they are more easily identifiable than any intermediate positions.

ITQ 4 You should have found that a shorter pendulum swings faster (more complete swings in the same time).

ITQ 5 Provided the initial length of your pendulum was over 1 metre, you should have been able to find all three lengths. They are approximately 1 m, 40 cm and 25 cm for 5, 8 and 10 swings in 10 seconds respectively.

ITQ 6 The period is defined as the time taken to complete one sequence of which the periodic motion is composed. In your case this is one complete swing. Thus if there are 5, 8 and 10 swings in 10 seconds, the corresponding periods would be 10 seconds/5 swings = 2 seconds per swing, $10/8 = 1\frac{1}{4}$ seconds and $10/10 = 1$ second.

By the way, you may have noticed that within the interval of 10 seconds each subsequent swing had smaller and smaller amplitude, that is the distance between the central (vertical) position and the extreme positions. But there was no noticeable difference in the period of subsequent swings (provided the length was kept constant).

ITQ 7 Provided the string of your pendulum was sufficiently long and thin and provided that you did not either deliberately or accidentally interfere with its swinging, the plane of swinging did not change. Thus you can conclude that the pendulum kept its plane of swing *regardless of the rotation of the arm* from which it was suspended.

ITQ 8 Going through the elliptical orbit in Figure 7a you would expect that the Earth would experience *two* complete seasonal cycles within one orbital period. There are two positions of the closest separation (that would presumably give summer); two positions of the largest separation (winter), etc.

The orbit in Figure 7b, which is circular but displaced so that the Sun is not at the centre of the circle, would lead to *one* cycle of seasons per period.

ITQ 9 In and around position 1, the British observer would see the Sun all the time. There would be no day-night cycle but continuous daylight. On the other hand, around position 3 Britain would have a long period of continuous darkness (facing away from the Sun). In positions 2 and 4, Britain would experience a regular day-night cycle, but so would all other places all over the Earth. The pattern would be identical everywhere; there would be no seasonal difference between Britain and Australia.

ITQ 10 Situation 1 in Figure 8a is characterized by the Sun facing the northern hemisphere of the Earth. There is an identical relative configuration of the Earth and the Sun in Figure 8b—the Sun to the left of the Earth. Similarly you can find to each numbered position in 8a an identical configuration in 8b. Thus an observer on the Earth could not tell which of the two bodies is orbiting—all observations would be the same in both alternatives.

ITQ 11 A 6; B 1; C 3; D 2.

ITQ 12 4—waning crescent
5—new moon (eclipsing the Sun)
7—first quarter
8—waxing gibbous

ITQ 13 A 7; B 2; C 5; D 8.

The answer to (a) is position 7, which according to ITQ 12 is the first quarter phase. The Moon in this phase is indeed seen in the afternoon and during the first half of the night. Similarly, position 2 corresponds to the waning gibbous phase, and the visibility deduced from Figure 14 agrees with the observed one (Figure 4). You should be able to verify in the same way your answers to (c) and (d).

ITQ 14 8 hours, since the arcs are about one-third of a full circle, and a full circle would be completed in 24 hours. Exposures as long as 12 hours would only be possible in winters, and would produce half circles. Exposure of 24 hours would ruin your picture (daylight).

SAQ answers and comments

SAQ 1 1 (O). The question states that the temperatures of both liquids are measured before as well as after heating, hence this is direct observation.

2 (A). Heat losses are not measured, but since both vessels are identical, it is reasonable to expect that heat losses to the outside environment (air, stands holding the vessels, etc.) are the same. Hence this is a reasonable assumption, *provided* that the two vessels are at the same temperature; at different temperatures this assumption becomes unreasonable.

3 (A). The question does not specify any monitoring of the mains supply to the heaters during the experiment, so this is again an assumption.

4 (O). As in 1.

5 (M). In order to explain the difference in temperature, the two liquids are represented as consisting of different particles, and the motion of particles is connected with temperature. It seems intuitively acceptable that the same amount of heat should produce more commotion in lighter particles than in heavy ones. You are not expected to assess whether this explanation is correct or not, but you should have been able to identify that this was a model attempting to explain an observed effect.

SAQ 2

Hemisphere	Configuration			
	1	2	3	4 ^a
north	winter	spring	summer	autumn
south	summer	autumn	winter	spring

In position 1, the northern hemisphere is tilted away from the Sun, so it will receive less light and heat and the Sun will appear to culminate low above the horizon (winter). By contrast, the southern hemisphere will be inclined towards the Sun—longer days, the Sun culminating high above the horizon, more light and heat (summer). In position 3, the relative inclination of the two hemispheres with respect to the Sun is reversed. In 2 and 4, both hemispheres go through the transitory mild periods.

SAQ 3 The only thing that matters in the determination of the season is the relative inclination of the hemisphere towards or away from the Sun. Thus position 1 in Figure 9a is the same as the position in Figure 9b, where the Sun is to the left of the Earth (northern hemisphere tilted away from the Sun—winter).

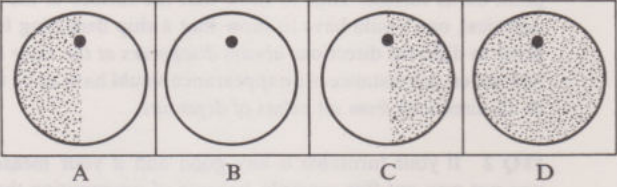
SAQ 4

6. Seasonal cycle	orbital period one solar year
7. Local variations of the seasonal cycle	axis of the Earth's spin tilted with respect to the plane of the orbit

SAQ 5 Obviously not. An eclipse can only occur if the three bodies lie in a straight line. This cannot happen in A, since the two points at which the lunar orbit crosses the plane of the Earth's orbit lie far away from the line connecting the Sun and the Earth.

SAQ 6 Only in or around situations B and D.

SAQ 7



- A—first quarter
- B—full moon
- C—last quarter
- D—new moon

SAQ 8 b, d, e. If the Moon did not spin (a), the surface feature would constantly face towards one and the same distant star. But since the Moon is moving around the Earth, the Earth-bound observer would be seeing gradually all the surface of the Moon.

If statement (c) were to be true, the Earth-bound observer would always see the same half of the lunar sphere, but all features away from the centre would rotate in circles.

If (f) were true, then during the 12 hours or so when the full Moon is continuously visible, its surface features could not remain steady. It would have to complete about half a turn during this time!

Finally, if the period of spin of the Moon were about one year then, during one lunar month (when the Moon completes one orbital circle around the Earth), a fixed surface feature would have turned by about 1/12 of a full circle. Thus the parts of the Moon visible at two consecutive full Moon phases would be different.

SAQ 9 A (2, 3); B (1, 2, 4, 7); C (4); D (5, 9); E (6). Note that observation 8, although very interesting, does not relate directly to any of the features A–E. Indirectly, it could relate to D, inasmuch as D relates to eclipses. If the apparent size of the Moon were very much smaller than that of the Sun, total eclipses of the Sun would be impossible. However, observation 8 will assume a great significance in Unit 2, when you will be considering the sizes of celestial bodies and their distances.

S101 Science: A Foundation Course

- 1 Science and the Planet Earth I
- 2 Measuring the Solar System
- 3 Motion under Gravity: a Scientific Theory
- 4 Earthquake Waves and the Earth's Interior
- 5 The Earth as a Magnet
- 6/7 Plate Tectonics: a Revolution in the Earth Sciences
- 8 Energy
- 9 Light: Waves or Particles?
- 10/11 Atomic Structure
- 12 Chemical Reactions
- 13 The Periodic Table and Chemical Bonding
- 14 Chemical Equilibrium
- 15 Chemical Energetics
- 16/17 The Chemistry of Carbon Compounds
- 18 Natural Selection
- 19 Genetics and Variation
- 20 Diversity and Evolution
- 21 Communities of Organisms
- 22 Physiological Regulation
- 23 Cell Structure and the Chemical Components of Cells
- 24 Chemical Reactions in the Cell
- 25 Genetics: Molecular Aspects
- 26 Geological Time
- 27 Earth Materials and Processes
- 28 Earth History
- 29 Quantum Theory
- 30 Quantum Theory of the Atom
- 31 The Search for Fundamental Particles
- 32 Science and the Planet Earth II

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